SUSTAINING EXPORT-ORIENTED VALUE CHAINS OF FARMED SEAFOOD IN CHINA

by

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For the memory of

respected teacher and dear friend

Dr. Yi YANG

Abstract

This thesis is intended to improve the understanding of China's evolving export-oriented farmed seafood systems, and in particularly, shrimp and tilapia farming value chains in Southern China. An integrated, systems thinking and interdisciplinary approach in which both top–down and bottom–up approaches were combined. The research moved from system reviews, to field surveys and workshops, and then to improving sustainability by Action Research (AR), in order to form a holistic understanding of sustainability at both national and local scales.

In the new millennium, the aquaculture sector has matured, and many factors now slow the growth rate of Chinese aquaculture production, such as increasing culture of high-value species and an emerging trend of extensification. There are been some strategy shifts in the aquaculture industry such as changing from a high production to high profit orientation and from causing environmental damage to ecological remediation. A key conclusion is that high growth rates, regularly used in policy dialogues, are misleading indicators and do not reflect, realistic or sustainable, growth profiles. Although overall Chinese aquaculture production is likely to further increase to meet an increasing and changing market demand, growth rates will decrease further. China already is and will continue to be a fisheries products net importer, however, if fishmeal excluded China will remain as a seafood net exporter.

The status and development of four internationally-traded farmed seafood, tilapia, penaeid shrimp, macrobrachium prawns and striped catfish in China were reviewed. China is the largest producer of tilapia, penaeid shrimp and macrobrachium prawns, and striped catfish is not produced in significant quantities due to climate limitations. Meanwhile, China is the largest exporter of tilapia,

the second largest exporter in the volume and third in value of shrimp in the world, while macrobrachium prawns mainly support domestic markets. Tilapia and penaeid shrimp were selected for further research.

An analysis of tilapia and shrimp farm scale indicators and their relationship to farming system and market orientation, farm intensification and performance was made. Farm area, both land and water area, labour, including paid and unpaid were effective indicators to distinguish farm scale. Small-scale farms had higher land productivity in production terms but no difference in value output term, and they had much lower labour productivity than medium and large-scale farms. Farming systems were also correlated with land and labour productivities. Market orientation was closely linked to farm scale as most farms with an export orientation required registration with CIQ (China Entry-Exit Inspection and Quarantine) and were mainly large-scale.

An assessment of local stakeholder sustainability perspectives along value chains revealed that more than 80% shrimp and tilapia farmers didn't want their children to continue basing their living on aquaculture; because they considered it hard work, high risk and poorly remunerated. Farming was comparative stable with few changes in the five years prior to the survey. Major sustainability factors identified by stakeholders included input costs, profit, water availability & quality and the weather, most of which were outside their control. The measurement of these sustainability factors was firstly proposed by stakeholders and then developed to a set of sustainability indicators (SIs).

Life cycle assessment (LCA) was used as evaluate the environmental performance of tilapia, pig and integrated tilapia-pig farming systems in China. Pig farming had higher environment impacts based on most impact categories than tilapia, and integrated farming systems. Sensitivity analysis

showed that improvements of 5% and 10% higher feed efficiency, reduction of fishmeal in feed to 1% level and use of EU electricity could significant reduce overall environmental impacts.

An action research (AR) approach was used to assess the practice of farm record keeping with farmers which were found to be generally low and a major constraint to improving product traceability increasingly demanded by consumers. Large scale and CIQ farms were more likely to keep records and for them to be detailed and analysed to inform improved management. Farmers' motivation, ability and capability and background had significant correlation with record keeping practice. Two major dilemmas were identified by the analysis. Easy-to-use farm record-keeping system more suitable for less formally educated farmers was a clear requirement but useful storage and analysis of farm data capacity requires sophisticated management tools such as a computer system. Another dilemma is the need for coercion by regulatory authorities or encouragement through provision of education and training in increasing on-farm record-keeping to a level required for international trade and, increasingly, domestic markets. "Precision aquaculture", value chain integrated solution, and further social-economic reforms were discussed.

Finally, sustainable intensification, diversification, and extensification were proposed as strategies for China to meet the challenges of globalization and the growing demands of export and domestic value chains. In order to enhance sustainability of the sector and provide opportunities for small-scale farmers, the current status and changes of the Chinese social, economic context, food safety and environments issues were discussed. Farmers' organizations, future consolidation, and land reforms were identified as key to the required changes of farmed seafood value chains.

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Declaration

The work described in this thesis was undertaken by the candidate, and embodies the results his own research. Where appropriate I have acknowledged the nature and extent of the work carried out by others. This thesis has not been submitted for any other degree.

Wenbo Zhang

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List of abbreviations

ACC (Aquaculture Certification Council)
AMOEBA (general method for ecosystem description and assessment (Dutch))
AQSIQ (General Administration of Quality Supervision, Inspection and Quarantine of the PRC)
AR (Action Research)
ASC (Aquaculture Stewardship Council)
ASEAN (Association of Southeast Asian Nations)
ASFIS (FAO Aquatic Sciences and Fisheries Information System)
BAP (Best Aquaculture Practices)
BRC (British Retail Consortium)
CBI (Centre for the Promotion of Imports from developing countries)
CCA (China Customs Administration)
CCP (Chinese Communist Party)
ChinaGAP (China Good Agricultural Practice)
CIQ (China Entry-Exit Inspection and Quarantine)
CNCA (The People's Republic of China on Certification and Accreditation)
CNY (China Yuan)
CP (Charoen Pokphand)
DMR (dry matter ratio)
DPSIR (Drivers–Pressure–State–Impact–Response)
EU (European Union)
EMS (Early mortality syndrome)
ESCM (Ethical supply chain management)
FAO (Food and Agriculture Organization)
FCRs (Food Conversion Ratios)
FDA (Food and Drug Administration inspections)
FIFO (Fish In Fish Out)
FMR (fish meal ratio)
FSC (Food Safety Committee of the State Council)
GAA-BAP (Global Aquaculture Alliance Best Aquaculture Practices)
GAC (Guide of Aquaculture Certification)
GlobalGAP (Global Good Agricultural Practices)
GIFT (Genetically Improved Farmed Tilapia)
GIS (Geographic Information System)
GMO (Genetically Modified Organism)
GMP (Good Manufacturing Practices)
GPS (Global Position System)
GSP (Good Supply Practice)
HACCP (Hazard Analysis Critical Control Point)
HRS (Household Responsibility System)
HS (Harmonized System)
IAAS (integrated agriculture aquaculture systems)
ISO (International Standardization Organization)

IFS (International Featured Standards)
IMTA (Integrated multi-trophic aquaculture)
LCA (Life cycle assessment)
MEY (Maximum Economic Yield)
MEP (Ministry of Environmental Protection of the People's Republic of China)
mmt (million metric ton)
MOA (Ministry of Agriculture of the People's Republic of China)
MOH (Ministry of Health Peoples Republic of China)
MSY (Maximum Sustainable Yield)
NBSO (Netherlands Business Support Office)
NSBC (National Statistical Bureau of China)
MSC (Marine Stewardship Council)
mt (metric tons)
NBSC (National Bureau of Statistics of China)
NCCAV (National Certification Committee of Aquatic and Bred Varieties)
NDRC (National Development and Reform Commission)
Nei (Not elsewhere included)
NFTEC (National Fisheries Technical Extension Center)
PCR (protein conversion ratio)
PL (Post larval)
PRC (People's Republic of China)
QS (QualitySafety)
RAS (Recirculating Aquaculture System)
RMB (Renminbi)
RSPCA (Royal Society for the Prevention of Cruelty to Animals)
SEAT (Sustaining Ethical Aquaculture Trade)
SIs (Sustainability Indicators)
SOA (State Oceanic Administration)
SOFIA (The State of World Fisheries and Aquaculture)
TMI (Tilapia Marketing Institute)
US (United States of America)
USD (US dollar)
WPR (waste production ratio)
WTO (World Trade Organization)

1. CHAPTER 1 General introduction

1.1. Research background

1.1.1. Aquaculture development

Today the world is experiencing a big transformation in its history. Industrialization and information techniques have brought much higher productivity to the modern world (Scarbrough & Corbett 2013). Globalization and free trade, together with specialization of production systems, have brought much cheaper raw materials and products (Kaukiainen 2014), thus more benefits to people. Rapid economic growth and urbanization are also improving the quality of life (Satterthwaite *et al.* 2010). However, major global problems have emerged along with social-economic development, from environmental degradation, to food security and climate change, all complicated by globalization. The magnitude and complexity of these problems needs sophisticated holistic and systematic thinking, knowledge, worldviews, and methods (Winowiecki *et al.* 2011).

"Bread is everything" is a famous Chinese belief. However, food security remains a challenge to the world (Godfray *et al.* 2010). The 1996 World Food Summit states "*food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life*" (Bondad-Reantaso *et al.* 2012). The inequitable distribution of the quality as well as the quantity of food causes malnutrition in some places and obesity in others (Popkin 2001; Popkin 2003). Seafood has been considered as healthy food, which provides the most important essential fatty acids (Aranceta & Pérez-Rodrigo 2012; Gjedrem *et al.* 2012), especially to infants and pregnant women (Oken *et al.*

2013). Seafood, a term that primarily includes fish and shellfish from the sea, now extends to all aquatic produce derived from both the wild capture and aquaculture, and from all water bodies such as marine water, brackishwater and freshwater[1]. Incomes growth and urbanisation has led a world-wide dietary transition to more meat, dairy, sugars and oils (Ericksen 2008), and seafood consumption is increasing rapidly (FAO 2012c).

Fisheries and aquaculture make crucial contributions to the world's well-being and prosperity and are on target to become the most important animal food source in the next decade (FAO 2012c). Production from capture fisheries cannot be increased and even could decline if not properly managed, leaving the world a significant food deficit (FAO 2012c; Garcia & Rosenberg 2010). As many of the world's wild-capture fisheries have collapsed, the efficiency of aquaculture has increased in line with globalization and dynamic consumer preferences, wild capture products are set to be gradually replaced by the adaptability, price and quality of farmed products (Robards & Greenberg 2007). In order to provide enough food for nine billion global population in 2050, aquaculture needs to expand quickly and lead the next food revolution (Stentiford *et al.* 2012).

Aquaculture or fish farming, despite its long history in China, was seen as one of emerging major industries in the 21th Century (Drucker 2012). While capture fisheries production has become limited by natural supplies since the mid-1980, the aquaculture sector has maintained an average annual growth rate of 8.7% worldwide since 1970 (FAO 2009b), the fast increased of aquaculture production and levelled off capture production was almost synchronised (Olsen *et al.* 2008). Aquaculture now contributes nearly 50% of global seafood consumption, and our dependence on fishing is being transformed to a farmed supply, as for all our staple food types (De Silva 2012).

[1] http://en.wikipedia.org/wiki/Seafood

Compared with capture fisheries and terrestrial animal husbandry, seafood is a more efficient converter of energy and protein and better in nutritional value (Costa-Pierce *et al.* 2011; Gjedrem *et al.* 2012). Production of seafood is expanding quickly and is expected to exceed that of beef, pork or poultry in the next decade, and aquaculture is the major reason for such an increase (FAO 2012c). In western countries, public perceptions of farmed seafood is that they are "cleaner" than comparable wild fish (Cole *et al.* 2009). Aquaculture has also altered the seafood supply pattern from seasonal supply by capture fisheries to almost all year-round supply (Sun & Che 2012).

Countries in the Asia-Pacific regions are the heart of the global aquaculture industry, together accounting for 89% of production by quantity and 77% of value in 2006 (FAO 2009b). Fast growth of the aquaculture industry in Asian countries was mainly driven by pre-existing aquaculture practices, population and economic growth, relaxed regulatory framework and expanding export opportunities (Bostock *et al.* 2010). Besides providing high quality protein, aquaculture development has a long list of social economic benefits such as food security, local employment, poverty reduction and rural development (Belton *et al.* 2011; Bhujel 2011; Brummett *et al.* 2011; Pillay 2000; Subasinghe *et al.* 2009).

1.1.2. Negative impact of aquaculture

Food production systems both for agriculture and aquaculture (including marine fisheries) have been criticised for their high usage of energy and resources as well as generating wastes along their product chains (Mungkung & Gheewala 2007). Aquaculture has been subjected to an increased level of public scrutiny for its environmental impact (De Silva 2012; Martinez-Porchas & Martinez-Cordova 2012), although sometimes it was over criticised as aquaculture is a "*soft target*" compared with other comparable sectors (New 2003). Aquaculture was compelled to develop under a burden of ethical and environmental constraints that did not restrict the formative period of agriculture (Shelton & Rothbard 2006).

The aquaculture sector depends on a wide range of inputs, with a similarly wide range of outputs and impacts (Muir 2005). Criticisms on aquaculture are also broad-spectrum and include destruction of natural ecosystems (e.g. mangrove forests); salinization/acidification of soils; pollution of water for human consumption; eutrophication and nitrification of effluent receiving ecosystems; ecological impacts in natural ecosystems because of the introduction of exotic species; ecological impacts caused by inadequate medication practices; changes on landscape and hydrological patterns; trapping and killing of eggs, larvae, juveniles, and adults of diverse organisms; and negative effect on fisheries (Martinez-Porchas & Martinez-Cordova 2012).

Developing countries often lack sophisticated resource management and rapid aquaculture development has negatively impacted on both social equity and the environment (Nunes *et al.* 2011). Short-term profit-seeking of farmers was often at the cost of environment, an icon of this was the *'rape and run'* practice in shrimp (*Penaeus spp*) farming, where ponds in mangrove areas were farmed intensively and quickly abandoned as observed in Thailand and the Philippines (Shang *et al.* 1998). The *'boom and bust'* production cycles of shrimp farming also created considerable environmental damage in rural communities (Szuster 2006). These external costs will be borne locally by future generations, potentially manifested through symptoms such as losses in ecosystem services, greater incidence of disease, and increased occurrence of harmful algal blooms (Nunes *et al.* 2011).

1.1.3. Seafood trade

Globalization and trade liberalization has reshaped the world agri-food supply, for example, it caused Europe to shift from being a net exporter to a net importer of agri-food products, and for developing countries to become more involved in world agricultural trade (Swinnen & Maertens 2007). With striking similarities to the experience of the agri-food and industrial production in the world, aquaculture activities have migrated to developing countries where production costs are lower and the environmental consequences of non-sustainable production are largely ignored (Nunes *et al.* 2011). Now developing countries contribute more than 70% of total capture fisheries and 90% aquaculture production (De Silva 2012). At the same time, clear trends show increased seafood trade net flows from developing countries to developed countries (FAO 2012c).

Seafood is now the most important global traded agriculture product, accounting for about 10% of total world agricultural exports in value terms (FAO 2012c). More than 37% (live weight equivalent) of total production enters international trade as various food and feed products (FAO 2009b). Seafood production and trade are extremely important for developing countries, providing both economic development and empowerment in terms of contribution to GDP, food security, poverty reduction, consumption, employment, catch value and exports (Bondad-Reantaso *et al.* 2012; McClanahan *et al.* 2013), the net export earnings of seafood have surpassed that of the more traditional export commodities such as coffee and rubber (De Silva 2012). Aquaculture growth is strongly influenced by markets, trade and consumption preferences with clear demands for the production of safe and quality products (Subasinghe *et al.* 2009), now aquaculture has developed into a highly globalized trade-dependent industry in both ways of raw material supply and product sales (Deutsch *et al.* 2007). Although most aquaculture products are consumed domestically, some species such as shrimp and tilapia (*Oreochromis spp.*) are important internationally traded commodities (New 2003). Some aquaculture products expanded quickly due to export market demand, such as the Vietnam's striped catfish (*Pangasianodon hypophthalmus*) and Chinese tilapias (*Oreochromis spp.*) are very successful in the international market (Hanson *et al.* 2010; De Silva & Phuong 2011).

In the book "The Wealth of Nations" by Adam Smith (1776), he argued *"if a foreign country can supply us with a commodity cheaper than we ourselves can make it, better buy it of them with some part of the produce of our own industry, employed in a way in which we have some advantage"*(Smith 1776). Later this was formulated to the concept of *'comparative advantage'* by David Ricardo, who found the costs of producing goods was different in different countries, each country can gain comparative advantage by specializing, thus international trade could be beneficial for all countries (Ricardo 1817). Many modern economic studies also revealed the statistically significant correlations between export expansion and economic growth (Chow 1987; Dutt & Ghosh 1994; Esfahani 1991; Jordaan & Eita 2007; Kavoussi 1984; Tyler 1981), especially in more advanced developing economies (Kavoussi 1984). Exports also lead to the economic structural transformation of the developing countries (Chow 1987). The positive export and economic association is often explained with the competition in world markets, such as efficiency of resource allocation, and economies of scale (Esfahani 1991).

Although globalization can increase economic efficiency, reduce trade barriers, liberalize investment, and will eventually benefit everyone, these changes have been distributed unequally both within and across national boundaries and caused greater inequality, whereas some countries or stakeholders have performed well in the global economic system, others have become marginalized and vulnerable (O'Brien & Leichenko 2003). Globalization also has great impact on agriculture, not just by providing more opportunities, but also exposing farmers to competition in the global market (O'Brien *et al.* 2004; Zhou 2011). It has been claimed that export-oriented industrial shrimp farming is both socially and environmentally unsustainable, especially for small-scale farmers who are vulnerable in the global value chain (Mialhe *et al.* 2013; Pradhan & Flaherty 2008; Rivera-Ferre 2009; Vanmulekom *et al.* 2006). Another extreme example is the high suicide rate among Indian farmers, which has been strongly linked to trade liberalisation and globalisation of agriculture (Shiva *et al.* 2000; Shiva 2004). Detailed causes included the introduction of monocultures of non-renewable seeds being hijacked by global corporations through patents and bio-piracy which caused high seed price; diversion from food crops to monocultures of cash crops, which created market dependency on corporate monopolies; and the collapse in the price of agricultural produce following the removal of price and import regulation, a direct result of trade liberalisation (Shiva *et al.* 2000; Shiva 2004).

Price fluctuations in the international market usually affect prices in the domestic market and incomes of small farmers (Huang & Rozelle 2006; Huang *et al.* 2012). Export instability had a significantly negative effect on the economy in sub-Saharan African countries (Gyimah-Brempong 1991). Trade conflicts amplified export instability, such as the EU ban on Bangladesh shrimp in 1997, the "catfish war" between US and Vietnam in 2002, anti-dumping of salmon and shrimp products from various developing countries by the US, and the "whitefish war" between EU and Vietnam, all caused huge negative impacts on exporting countries (Asche & Khatun 2006; Belton *et al.* 2011; Cato & Lima Dos Santos 1998; Little *et al.* 2012). Farmed seafood does not just compete within the same species in the global market, inter-species competition among substitutes such as tilapia and catfish and similar small whitefish occurs in the same market segments, along with globalization means farmers need to be competitive on a global scale, the production of specific countries, regions or species may be reduced if they are not competitive (Asche *et al.* 2008).

The export of high value products such as crustaceans was believed to make a positive contribution to food security in both producing and exporting countries by enabling producers to buy lower value products on the world market (Bondad-Reantaso *et al.* 2012). However, free trade may exacerbate existing imbalances in seafood consumption between industrialized and developing countries and among economic classes (New 2003). It has been found while aquaculture and international trade offered profit and luxury food for developed countries, and alarmingly little food security and improved living standards to the nations where cultivation occurs (Islam & Wahab 2005; Pradhan & Flaherty 2008; Nunes *et al.* 2011; Vanmulekom *et al.* 2006).

Environmental problems can shift from one site to another or from the local scale to global scale, when alternative farming systems or practice were adopted (Ayer & Tyedmers 2009). Global product chains can be seen as networks through which environmental and social impacts are transferred across boundaries (Boons *et al.* 2012). By increasing food imports and reducing food production, developed countries have transferred food producing environmental impacts to developing countries where technology levels are usually lower and environmental risk probably higher than that of developed countries (Bostock *et al.* 2010). Trade has made environmental impacts disproportionate, a significant emission deficit has been observed among importing countries, indicating that post-Kyoto agreements must focus not only on traded goods but also on the environmental efficiency of domestic production chains (López *et al.* 2013).

Accessing international markets requires meeting stringent standards. There are legislative as well as non-legislative requirements, the former include various regulations for food safety and traceability, and the latter are imposed mainly by supermarkets and large restaurant chains, who want to differentiate their products to gain a competitive advantage (CBI 2013c). The global community only recently endorsed certification guidelines for aquaculture, which encompass production practices, environmental integrity and social harmony, and overall sustainability (De Silva 2012). The impact of global competition is forcing farmers to adopt international standards, especially in food safety concerns (Ito 2004). Normally these international standards have higher requirement than the national standards in developing countries (WTO 1998). Many aquaculture certification themes were developed and applied, such as GLOBALG.A.P., Aquaculture Stewardship Council (ASC), Best Aquaculture Practices (BAP), and latest animal welfare certifications such as Animal Welfare Approved (Animal Welfare Approved 2013; ASC 2012; Baier 2011; BAP 2008; Berrill *et al.* 2012; Black & Glatz 2011; GLOBALG.A.P. 2013). Some certification schemes focus more on food safety standards, such as the British Retail Consortium (BRC) and International Featured Standards (IFS), while others have broader sustainability goals, such as GLOBALG.A.P., ASC, and Naturland (CBI 2013c). However, market-based sustainability standards and certifications such as Marine Stewardship Council (MSC) have been criticised for failure to show positive environmental impacts, but having marginalized Southern fisheries, especially in low-income countries. Some have concluded that such certifications such as MSC have created a market for sustainable fish rather than sustainable fisheries (Ponte 2012). Small-scale farms have also found difficulty in following these higher standards and have struggled to survive (Ito 2004).

1.1.4. Sustainability and its implications in aquaculture and trade

In order to eliminate existing negative impacts on the environment and society, while maintaining social economic development, the concept of sustainability or sustainable development was developed (Bell & Morse 2008). Sustainable development is a challenging and multi-dimensional abstract concept with many explanations and interpretations attempting to provide a more workable statement of its meaning (Mampan *et al.* 2011). Sustainability is not just about the environment or the conservation of natural resources, socioeconomic factors are also important (Edwards & Demaine 1998). Single issue standards in particular may ignore this aspect, for example, animal welfare standards need also to attend to the welfare of the owners and operators (New 2003). The definition of the word sustainable is to *"keep going indefinitely"*, although in practice this has been modified to include an element of responsibility (e.g. for people, for the environment, for the equitable use of resources, etc.) (New 2003). Since sustainability was embedded into the global agenda at the Rio Summit in 1992, Brundtland's (1987, p. 43) *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* has become the most widely accepted definition of sustainability (Graymore *et al.* 2009). The concept is also highly normative, value loaded, and subject to many interpretations (Stel 2003). Depending upon the costs incurred in attaining sustainability, it has been conceived as either strong or weak sustainability (Neumayer 2003). In strong sustainability, there is little, if any, consideration of the financial or other costs of attaining sustainability, while weak sustainability means the cost of attainment (financial or otherwise) are important and are typically based on a cost-benefit analysis, which inevitably involves trade-offs between environment, social and economic benefits (Bell & Morse 2008). Sustainable development has lately become perceived as a combination of three dimensions or ‘pillars’, namely, the environmental (ecological), economic, and social dimensions (Lehtonen 2004). The three-pillar concept of social, environmental and economic aspects of sustainability also implies trade-offs among them (Iglesias & Buono 2009). For example, faced with hunger and starvation, priority will not be given to biodiversity conservation (Mampan *et al.* 2011). More complicated trade-offs can be found along seafood global value chains among environmental, governance, socioeconomic, food security, corruption, seafood market, and corporate social responsibility issues (Villasante *et al.* 2012). Different pillars also could be integrated, for example, environmentally detrimental practices will in general hamper productivity growth or increase production cost, and make such farmers economically uncompetitive (Asche *et al.* 2008).

Moving to an industrial society and the industrial or scientific revolution is often calle*d ‘development’*, but such development was seen as the major cause of unsustainability (Edwards & Demaine 1998). The Green revolution is an example of unbalanced development among different pillars of sustainability and thus unsustainable, since although it ‘*saved the world*‘ from hunger and malnutrition through higher productivity in the 1960s and 1970s it also caused serious environmental impacts such as excessive use of inorganic fertilizers and pesticides, degradation of soil quality, depletion of both surface and ground water resources, loss of biodiversity, and social inequality between rich and poor farmers and between men and women (Mampan *et al.* 2011; Swaminathan 2006). For agriculture, a greener revolution is needed, which is based on the total costs and benefits, including agriculture-dependent gains and losses in values of such ecosystem goods and services as potable water, biodiversity, carbon storage, pest control, pollination, fisheries, and recreation (Swaminathan 2006; Tilman *et al.* 2001).

Increasing global demand for seafood and level or declining fisheries requires further expansion and intensification of aquaculture (Stentiford *et al.* 2012). Indeed, over the past two decades, aquaculture systems have been intensified significantly, moving from traditional unmanaged semi-natural methods towards more intensive pond, tank and cage-based techniques (Muir 2005). The concept of the *"Blue Revolution*" was advocated and characterised by higher levels of intensification through agro-industrially manufactured pelleted feed, has attracted social and environmental concerns (Edwards 2011a). The ongoing *"Blue Revolution"* should learn from criticisms of *"Green Revolution"* for its high in social and environmental costs (Diana *et al.* 2013; Edwards & Demaine 1998; Edwards 2010) and the *"Blue Revolution"* must '*green up*' (Costa-Pierce 2007).

Shrimp can be seen as an excellent case to show both the positive and negative impacts of its development and global trade (Rivera-Ferre 2009). The costs of waste treatment or pollution prevention, or the taxes on discharging effluents are not usually included in the conventional financial analysis, but they are important cost items for a sustainable operation (Shang *et al.* 1998). For example, although shrimp and marine fish farming maybe profitable, this is often at some cost to local resources and environments (Muir 2005). Environment cost and economic benefit analysis shows shrimp farming profit is lower than ecosystem services cost, in another word, shrimp farming is losing money if environment costs are accounted into the total production cost (Rivera-Ferre 2009). Global competition, on its dark side, has tended to mainly ignore social and environmental costs and focused on production costs. However, this may reflect consumers unwillingness to pay more for their food when the price of food includes social and environmental costs, and price increases jeopardize local export industries (Rivera-Ferre 2009).

Aquaculture development needs to be balanced between economic benefits and environmental and social sustainability (Grigorakis & Rigos 2011). A framework for sustainable aquaculture systems was developed, which comprised of three interrelated aspects: production technology, social and economic factors, and environmental aspects (Figure 1.1).

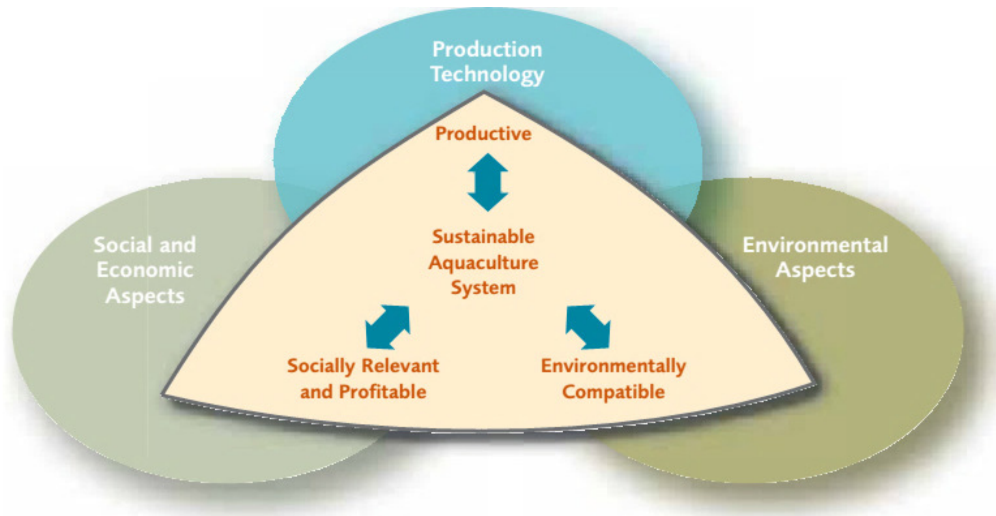


Figure 1.1 Sustainable aquaculture systems involve consideration of production technology, social and economic aspects, and environmental aspects
(source: AIT 1994; Edwards & Demaine 1998; Little & Edwards 2003)

A general separation of net producing and net consuming nations for seafood has created a truly globalised food industry (Stentiford *et al.* 2012). The processing of seafood often occurs in multiple locations, with fish caught in one country, processed in a second, and finally sold and consumed in a third (Mansfield 2003; Miller *et al.* 2012). These cause concerns in both exporting developing countries and importing developed countries. On the one hand, seafood trade is extremely important for developing countries for economic growth and employment, on the other hand, developed countries such as the EU, Japan and US now are highly dependent on imported seafood following serious depletion of local fisheries resources (Swartz *et al.* 2010), for example, seafood supply in Ireland has gradually moved from local fish landings to imports, aquaculture production (Miller *et al.* 2012). The future seafood security and sustainable seafood consumption in western countries has been increasingly debated (Little *et al.* 2012). The application of the product life cycle analytical point of view in policy and practice is complicated by the fact that the activities that constitute a product chain are performed by economic actors embedded in networks of relationships that are increasingly global (Boons *et al.* 2012). Along with the rapid increase in the seafood trade, the sustainability of aquaculture trade is now in the limelight (Ababouch 2006; Ayer *et al.* 2009; Cole *et al.* 2009; Koldewey & Martin-Smith 2010; Merino *et al.* 2010).

1.1.5. Sustainability measurement

Sustainable aquaculture development and trade requires sufficient qualitative and quantitative information to decision-makers, ecosystem managers and farmers (Nobre *et al.* 2010). The concept of "*sustainable aquaculture*" needs not only being well defined, but also that it can be measured (Boyd *et al.* 2007). Although the concept of sustainable farming is well understood by many researchers, the methodology for measurement and implementing it is less developed (Srinath *et al.* 2000).

Aquaculture research has primarily focused on biological and environmental sciences which is a narrow disciplinary research, and social and economic aspects of aquaculture has been largely ignored (Edwards *et al.* 1997; Edwards & Demaine 1998). The most used indicators of resource use i.e. efficiency and environmental performance in aquaculture are more focused on farm level practice, such as the commonly used indicators Food Conversion Ratios (FCRs) and Fish In Fish Out (FIFO) ratios (Costa-Pierce *et al.* 2011). Less commonly used indicators include dry weight (water removed) FCR, the dry matter ratio (DMR), the waste production ratio (WPR), the protein conversion ratio (PCR), and the fish meal ratio (FMR) (Boyd *et al.* 2007). From an ecosystem perspective, different evaluation tools are available, such as ecological status evaluation methods, spatial analysis and Geographic Information System (GIS), and other detailed tools that focus more on the carrying capacity of aquaculture production (Nunes *et al.* 2011). Broader indicator-based approaches were developed to quantify the degree of environmental impact at both local and global scales, such as the farmer sustainability index and life cycle assessment (LCA) (van der Werf & Petit 2002).

Such tools are applied at different scales of space (farm to system level), time (seasonal to annual and/or long-term analysis) and complexity (ease of use to complex process-based modelling) (Nunes *et al.* 2011). Among these tools, LCA has become increasingly used for aquaculture development assessment (Henriksson *et al.* 2011), as it can provide a comprehensive, holistic approach for assessing the 'cradle-to-grave' sustainability of a product or process (Kruse *et al.* 2008). LCA is far beyond the 'farm-to-fork' approach, as it includes impact assessment of all actions and means required to produce, distribute and use a product, from raw material use, infrastructures, energy, processing and all the emissions (in air, water and soil) linked to the product or process (Martins *et al.* 2010). LCA also can analyse environmental impacts at different scale or different stages and identifies how environment impacts migrate between different scales or stages (Ayer & Tyedmers 2009; Cao *et al.* 2011). In China, LCA of both farming systems and at the national level are urgently required to identify hot spots and best practices to inform future development (Zhang *et al.* 2014).

However, in common with other environmental performance evaluation indicators and indicator based approaches, LCA is primarily an environmental assessment tool, it doesn't include temporal and geographical differences as well as social and economic aspects (Mungkung & Gheewala 2007). Moreover, these tools are mainly reductionist expert-led (top–down) approaches (Bell & Morse 2008), and cannot resolve broader questions such as seafood traceability, which need understanding of its concepts and integration of multidisciplinary knowledge (Porto *et al.* 2011). Along with social development, more democratic, community-based (bottom–up) participatory approaches were emphasized in order to achieve more ethical development (Bell & Morse 2008).

The intellectual origins of participation in agricultural research can be related to the broader development of action research (AR) approaches within the development community (Martin & Sherington 1997). AR in its nature is trans-disciplinary, which can address multiple objectives, including improved and sustainable livelihoods and a greater understanding of the landscape dynamics and trends of the resources in complex system (Nagabhatla & Sheriff 2012). AR practice, essentially is an action learning cycle, through a systemic approach to problem-solving that can be applied in a systemic manner (Bell & Morse 2008). Instead of formal planning processes and conventional top-down research paradigms, ARs provide an alternative way to empower disadvantaged groups by its focus on local knowledge and management capacity (Martin & Sherington 1997). ARs also were used to promote small-scale aquaculture by farmers and extension agents joint learning exercises (Brummett *et al.* 2011) in order to deal with real world situations and solve specific problems, and thus improve sustainability (Riisgaard *et al.* 2010).

In general, there is a lack of a comprehensive theoretical framework for understanding aquaculture and seafood trade sustainable development and its multi-disciplinary complexities, since the range of published definitions is vague and it remains a confused topic fraught with contradictions (Jabareen 2006; Mampan *et al.* 2011). The "systemic approach" was introduced as an alternative paradigm of thinking and problem-solving for sustainable development, distinguished by traditional scientific or technocratic approach, system approaches as wholes are fundamental and need to be understood in their entirety (Bell & Morse 2008). At the same time, sustainability issues can be divided as micro level and macro level, in which micro level mainly refers to the farm level, and macro level include global, national, regional and watershed contexts (Little & Edwards 2003). Different analysis tools with different levels of complexity may be complementary and can be combined for integrated assessment and play in multi-method evaluation frameworks (Nunes *et al.* 2011). Thus, a multidisciplinary, holistic or systems approach is required to address social, economic and environmental aspects of the aquaculture industry (Edwards *et al.* 1997).

1.1.6. Aquaculture and farmed seafood trade in China

China is perceived as the world's seafood juggernaut, the world's largest producer, exporter, and consumer, representing roughly a third of the global market (Cooke 2012), especially farmed seafood such as tilapias and shrimps (FAO 2009b). China has been responsible for most of the increase in world seafood production increase, particularly from aquaculture (FAO 2012c). The fisheries sector is one of the most important protein sources for Chinese people, and has made a major contribution in dealing with the country's food security challenge. In 2011, Chinese aquaculture production exceeded 40 mmt (million metric tons), accounting for 71.8% of total Chinese fisheries production (56 mmt) (MOA 2012). This growth in output has had a huge impact on the global aquaculture sector. FAO data suggest that while farmed aquaculture products now account for half of all aquatic foods (the other half being from capture fisheries), without China, the figure drops to less than 25% (Costa-Pierce 2010). The tenfold increase in fisheries production growth since 1980s has been linked to China's capability to feed 21% of the global population with only 7% of the world's arable land and 18% of the world's grain production (Yang, 2006). Fisheries and aquaculture have been the fastest-growing component of agriculture in China, the share of aquaculture in agriculture grew from 2% in 1970s to 10% in 2000 (Huang *et al.* 2012). The fast aquaculture production increase in China was mainly driven by the growing demand from both export and domestic markets and the improved production technologies such as pellet feeds (Xie *et al.* 2013). Fisheries, especially aquaculture has received strong support from government and the future of aquaculture in China appears to be bright (Kang 2009).

Chinese aquaculture has demonstrated two major trends (1) towards intensification of farming systems and (2) greater species and system diversification (Miao & Liao, 2007; Zhou, 2007). While the average yield of farmed seafood doubled from 1.7 mt (metric tons) ha^{-1} in 1990 to almost 4 mt ha^{-1} in 2000 a concomitant rise in the diversity of species, many of them exotics, used in aquaculture has been matched by an increase in the variety of culture systems, making the sector more dynamic than other food production subsectors in China (Liu & Li, 2010; Miao, 2010). Finfish remain the most important aquaculture products, although both molluscs and crustacean have grown rapidly since the 1990s (MOA 2012). Now more than 200 aquatic species are being farmed (Song *et al.* 2010), confirming both the novelty-seeking tradition of China's entrepreneurial aquaculture industry and that diversification has been an official goal of the industry (Liu & Li, 2010). It also suggests a lack of effective regulation on exotic species introduction (Song *et al.* 2010). By 2006, 129 aquatic species had been introduced into China, including 89 kinds of fish and 10 kinds of shrimp and prawn (Wang & Cao, 2006). Farming system diversification is mainly driven by the introduction of species and varieties, the policy of economic reform, market demand, and natural disasters (Phong *et al.* 2007).

However, aquaculture in China was seen as large, but not competitive in global terms lacking in leading science and technology (Li *et al.* 2006; NBSO 2010a). Compared with the aquaculture industry in developed countries such as industrialized cage farming in Norway, aquaculture in

China is still traditional, '*low tech*' and natural resource dependent with small-scale farms and diversified species and practice (Mai & Tan 2002; NBSO 2010a; Zhang & Rørtveit 2005). The huge difference between the aquaculture industry in China and developed countries can be measured by *per capita* productivity (NBSO 2010a). The *per capita* productivity of China's aquaculture industry was only seven mt in 2010, compared with Norway's 187 mt and the North American average of 183.2 mt (FAO 2012c).

Aquaculture in China has also been criticised as one of the major contributors to the increasing level of organic waste and toxic compounds in the environment (Cao *et al.* 2007). Environmental investigations of coastal China's suggest aquaculture is one of major sources for heavy mental and antibiotic pollution (Zhang *et al.* 2012; Zheng *et al.* 2012). Increasing aquaculture intensification in China is affecting the carrying capacity of the environment and therefore threatens further development (Kang 2009). Aquaculture expansion in China was seen as being dependent on depleting natural resources, which makes it unsustainable (NBSO 2010a).

China became a member country of the World Trade Organization (WTO) in 2001 and resultant lowering of Chinese tariffs stimulated a rapid expansion in the seafood trade (Dey *et al.* 2005; Xiao 2007), and also helped encourage a surge of Chinese food industry investment by both Chinese and multinational companies (Gale & Buzby 2009). China's seafood imports were dominated by fishmeal and through the so called "processing trade" in which raw material is imported for processing and then re-exported, while exports were dominated by farmed seafood species such as shrimp, tilapia, eel, channel catfish and large yellow croaker (Zhang *et al.* 2014). Traditional carps farmed in freshwater still dominated Chinese aquaculture production, accounting for 41.5% of total aquaculture production in 2010 (MOA 2012). Now carps remain popular in domestic markets, but they have limited demand in international markets, the rise of China as an exporter has been linked to shrimp from coastal ponds, and more recently tilapias from inland systems.

China's aquaculture is at a crucial change stage in changing from traditional farming to modern industry (Gui & Zhu 2012). China's aquaculture has its own distinctive characteristics, however, at present no systematic approach to understanding the aquaculture and farmed seafood export value chain as a whole in China exists as well its sustainability implications, China's aquaculture has been largely unknown to the world due to cultural differences and, most importantly, the language barrier but also being perceived by some as a black box (Chiu *et al.* 2013). The characteristics of tilapia and shrimp farming in China in comparison to elsewhere are also likely to impact on the sustainability of their production and export trade as consumers respond to environmental and other credence values (Little *et al.* 2008).

1.2. Objectives and research questions

This thesis is intended to improve the understanding of China's evolving export-oriented farmed seafood systems, and in particular, shrimp and tilapia farming value chains in Southern China. To accomplish this aim, an integrated, systems thinking and interdisciplinary approach in which both top–down and bottom–up approaches were combined. The research moved from system reviews, to field survey and then to improving sustainability by Action Research (AR), in order to form a holistic understanding of sustainability at both national and local scales.

The thesis attempts to answer the following research questions:

1 What is the social-economic background to, status and trends of, aquaculture value chains, and in particularly, shrimp and tilapia farming value chain in China?

2 How are farmed seafood value chain members' perceptions, and in particular producers, practices related to and affect sustainable development?

3 How can value chain performance and sustainability be assessed using the LCA evaluation tool?

4 How can shrimp and tilapia farming sustainability be improved through Action Research?

1.3. Contributions

This thesis was a component of the Sustaining Ethical Aquaculture Trade (SEAT) project research, much of which was a collective endeavour. All major chapters had contributions by other team members. Detailed contributions for research design, data collection, data analysis, and writing are presented in Appendix 1.

2. CHAPTER 2: General methodology

The methodology is based on an interdisciplinary approach from system review, to field survey and then to improving sustainability by Action Research (AR). The general methods follow a systemic sustainability analysis approach, starting with system context understanding before moving to a participatory approach which involves stakeholders participants, which is a holistic process approach with less control over the problem – participative approaches (Bell & Morse 2008).

2.1. Introduction of chapters

The thesis constitutes five stages and nine chapters starting from analyses of secondary literature in chapters 3 and 4 to primary data based research in chapters 5, 6 and 7. Chapter 8 presents information based on action research with stakeholders (Figure 2.1).

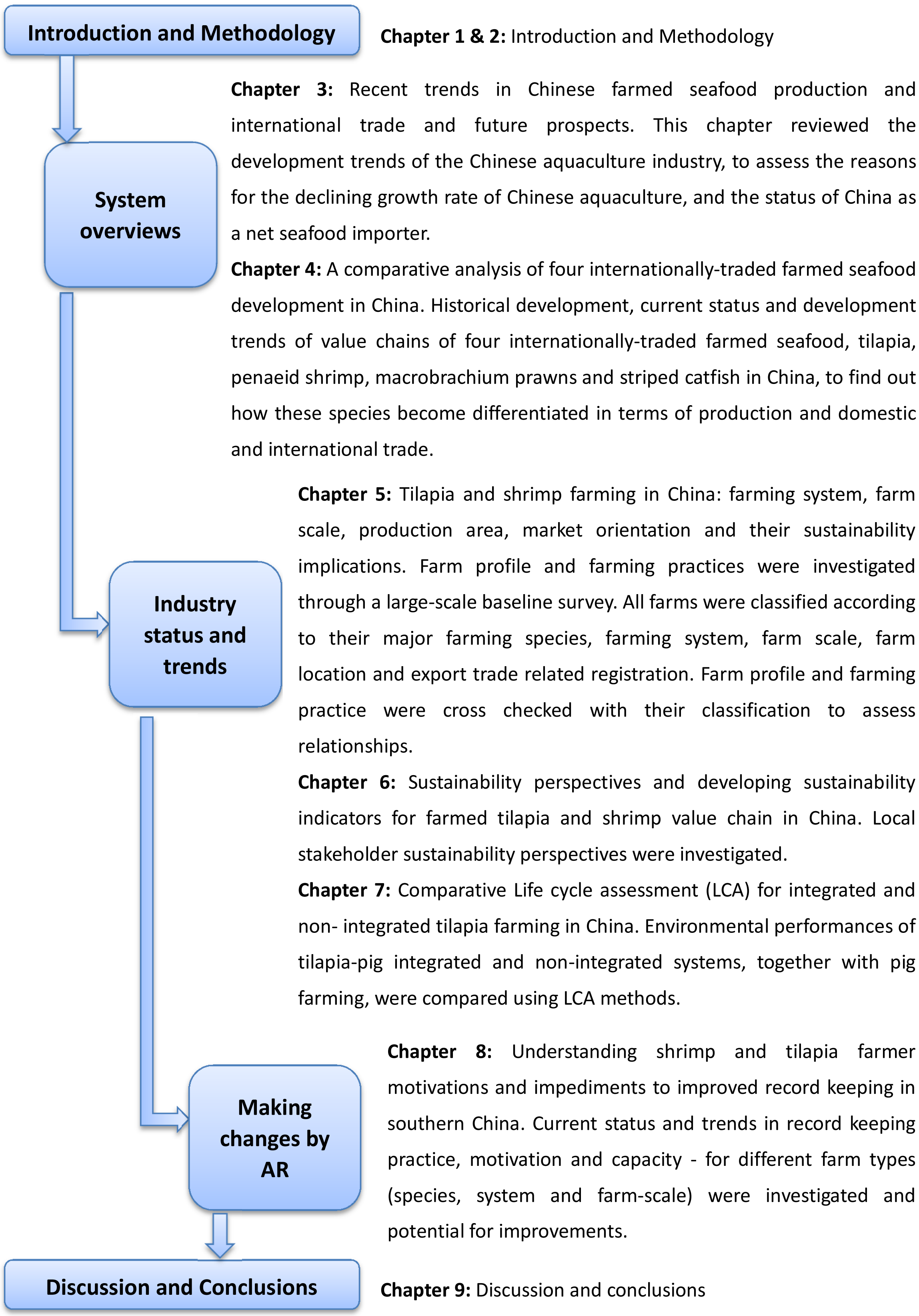


Figure 2.1 Thesis framework

2.2. System reviews

Sustainability is a highly complex and contested term that is open to a wide variety of interpretations and conceptualizations. As a first step establishing human and environmental contexts is critical (Bell & Morse 2008). Sustainable development practitioners should start by defining stakeholders, systems of interest, problems, goals and strategies through qualitative research (Reed *et al.* 2006). The inclusion of both bottom–up and top–down stages is vital to achieve the hybrid knowledge required to provide a more nuanced understanding of environmental, social and economic system interactions that is required to provide more informed inputs to local sustainable development initiatives (Reed *et al.* 2006).

Thus the development status and trends of China's aquaculture industry and export-oriented farmed seafood value chain was reviewed. At the outset, in a system review stage, the historical development, current status and development trends of the Chinese aquaculture sector and four important farmed seafood in the global market, namely shrimps, tilapias, prawns, and striped catfish were reviewed in chapter 3 and 4 respectively. Online databases, peer-reviewed papers and grey literature, in both English and Chinese language, were reviewed to form a holistic picture. Scenarios were made to test hypotheses based on research questions to explore different future development strategies.

Based on system reviews, primary system boundaries, such as major research species, research area, value chain stakeholders and farming systems, were set for following chapters. Whiteleg shrimp *(Litopenaeus vannamei,* formerly *Penaeus vannamei)* and tilapias were selected as major research species. Major producing and exporting areas for *L. vannamei* and tilapias were selected as major study areas, namely Zhanjiang district in Guangdong province for shrimp, Maoming district in Guangdong province and Wenchang county in Hainan province for tilapia.

2.3. Industry status and trends

In the industry status and trends research stage, varied field survey techniques were adopted from snowball sampling (Goodman 1961) in the scoping and piloting to a complex multistage (stratified-purposive-random) sampling process culminating in the baseline survey.

2.3.1. Piloting

Scoping fieldwork started in October 2009 and ended in July 2010, data collection methods including exploratory participatory methods such as key informant interviews, stakeholder interviews and multiple focus group meetings. Key informants were identified through initial contacts of the researchers and their colleagues and then by snowball sampling (Goodman 1961) along the value chain.

2.3.2. Baseline survey

The survey sample design and site selection was based on the boundaries set in the scoping period in a multi-stage sampling process, and refers to the progressive resolution from larger to smaller administrative units, e.g. province to district, sub-district, etc. using aggregate secondary data at each level as the basic sample units, then narrowed down geographical focus in the next stage. At the final level Google earth satellite imagines were adopted for farming cluster random selection and individual enterprises (farms) random selection. The target sample size was set at 400 farms consisting of 200 shrimp and 200 tilapia farms respectively. The number of farms sampled per cluster ranged from 20 – 30 farms and therefore the number of clusters ranged from seven to 10 per species. The individual enterprises (farms) selection was also based on associated indicators, including primary farming species, farming system, farm scale and China Entry-Exit Inspection and Quarantine Bureau (CIQ) registration status, which related to export trade. At the first stage, six shrimp and tilapia farms were selected for survey piloting and questionnaire testing in Shanghai municipality directly under the Central Government, Zhanjiang district and Maoming district of Guangdong Province. The survey lasted five months from 25th October 2010 to 10th March 2011, during which time a total 407 farms were surveyed, included 200 shrimp farms in Zhanjiang district of Guangdong province, 135 tilapia farms in Maoming district of Guangdong province and 72 tilapia farms in Wenchang county of Hainan province.

2.3.3. State of System (SoS) workshop

A State of the System (SoS) workshop was conducted to review and summarise the outcomes of the systems analyses conducted during the scoping and baseline survey. The workshop was held in Zhanjiang, Guangdong, China, in April, 2011. 41 stakeholders were present at the workshop representing six stakeholder groups i.e. feed and chemical suppliers, shrimp farmers, processors, professionals, hatcheries and tilapia farmers. Some journalists also joined the workshop.

2.3.4. Follow-up survey

After the baseline survey, major constraints for shrimps and tilapias farming emerged, such as Early Mortality Syndrome (EMS) disease for shrimp and low farm gate price and disease for tilapia. In order to assess farm-level changes two years after completion of the baseline survey, a follow-up survey was conducted based on the same sample. The questionnaires were derived from a similar exercise in Vietnam but adjusted for the Chinese context. The follow-up survey was based mainly on telephone interviews of 20 minute duration.

2.3.1. In-depth LCA survey

The baseline survey provided most of the data needed to model on-farm practices for the LCA study but additional data was collected directly from hatcheries, feed producers, processor, fishing vessels and fishmeal factories in Guangdong and Hainan province. Data was collected through face-to-face interviews with key-informants and individual farmers/fishermen. Besides primary data, secondary data needed for LCA models also was collected from journal papers, books, reports and online databases. Ecoinvent® database version 3.0 was used for baseline background data. Country specific background data such as energy sources, agriculture products and feed raw materials were collected from statistical yearbooks, online databases, books, peer-reviewed papers in both English and Chinese language, and grey literature such as industry reports and magazines.

2.4. Action research

The methods used, modified from AR framework developed by the SEAT project (Waley 2010), are presented in Chapter 8.

2.5. Data management and analysis

Data was subjected to descriptive, qualitative and quantitative analysis. All meta-data collected were catalogued in both English and the Chinese before entering into EXCEL software (Microsoft Office 2010). A fully normalised relational database was developed using ACCESS software (Microsoft Office 2010) for data management and analytical purposes. Data collected from baseline survey, SoS workshop and follow-up survey was inputted into ACCESS database. This comprised 41 individual data tables together with associated tables for each pre-coded response system. Data used for analysis was retrieved from the ACCESS database using data-query tools. Data collected in the in-depth LCA survey and AR was managed by EXCEL. Excel was also used to calculate and draw data maps based on original data maps from ExcelPro.blog.sohu.com.

Farm survey data was analysed by SPSS 21 statistic software (IBM 2013). Because samples were selected independently, independent-samples Kruskal-Wallis test was used for significance test for continues variable and Pearson Chi-Square was used to test for dichotomy variables[2].

CMLCA v5.2 software was employed (http://www.cmlca.eu/) for LCA study, and CML baseline method was adopted for Life Cycle Impact assessment (LCIA) (Guinée *et al.* 2002).

[2] Dichotomous (outcome or variable) means "having only two possible values", e.g. "yes/no", "male/female", "head/tail", "age > 35 / age <= 35" etc.

3. Chapter 3 Recent trends in Chinese farmed seafood production and international trade and future prospects

3.1. Introduction

Although aquaculture has a long history in China, modern aquaculture and large-scale production only began after the founding of the People's Republic of China (PRC) in 1949, increased rapidly after China opened up to the outside world in the 1980s and has become one of the fastest growing food production sectors in the country (FAO 2005; Publishers 2001; Wang 2000). Aquaculture production surpassed that of capture fisheries in 1985 and has dominated seafood production since then (Figure 3.1)

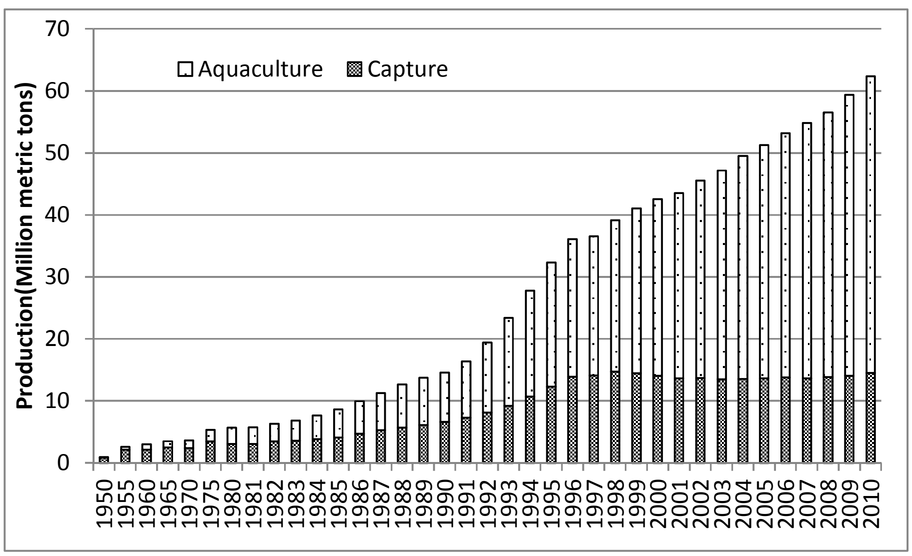


Figure 3.1 Fisheries production (with algae wet weight) from aquaculture and capture during 1950-2010 in China

(source: (FAO 2012a))

Seafood production growth in China is attributable to the country's rapid economic growth, rising disposable incomes and greater consumption of seafood, together with strong growth of aquatic exports (Bean & Wu 2005). Since 2002, China has been by far the leading fish exporter, contributing almost 10% of 2008 world exports of fish and fishery products (FAO 2010). A recent study shows China accounts for 10% by weight and 13% by value of global trade in fishery products (Blomeyer *et al.* 2012).

However, a series of FAO SOFIA (The State of World Fisheries and Aquaculture) reports stated China's aquaculture production growth slowed down since 2000s (FAO 2007; FAO 2009b; FAO 2010) but no specific reasons have been given. Data from FAO fishstatJ database shows the average annual growth rate of Chinese aquaculture decreased from 12% in 1980s and 13.6% in 1990s to 5.5% in 2000s and 5.6% in 2010 (Figure 3.2) (FAO 2012a). In the meantime, the fast growth of aquaculture in other countries, especially several Asia countries, reduced the proportion of China's aquaculture production of the global harvest from its highest level of about 66% during the period 1996–2000 to 61.4% in 2010 (FAO 2012c).

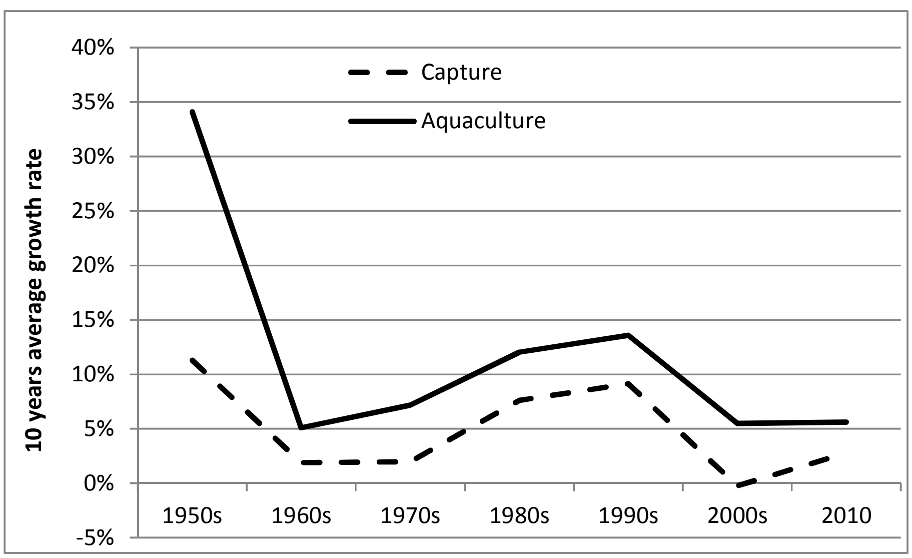


Figure 3.2 10 year average annual growth rate of China's aquaculture and capture fisheries production (sources: FAO fishstatJ 2012).

In parallel, over the last three decades, China has experienced rapid economic and social development leading to China becoming the world's largest exporter and manufacturer, and its second largest economy (World Bank 2012); the Chinese economy is now viewed as the *"factory to the world"* (Veeck 2008). Its size, production capacity, consumer needs, competitive advantages, and large domestic market make China an exceptional actor in the global economic and geostrategic context, which has undergone very significant changes in recent years (Villasante *et al.* 2013). The emergence of China as an economic giant has caused concern that its rapid transition would upset the fragile equilibrium of global food markets (Huang *et al.* 1999). As global trade in food and agriculture dramatically increased in the last decade (Busch & Bain 2004), the impacts of the huge and increasing Chinese population on world food supplies have created uncertainty (Brown 1995).

Statistics show seafood consumption in China has increased rapidly (Wang *et al.* 2009) and will continue to grow based on the increasing population, the rise of gross domestic product (GDP) and *per capita* income, awareness of seafood being healthy, urbanization and the currently low-level and potential for increasing seafood consumption in western regions of the country (Clarke 2009; Chen 2007; New Zealand Trade and Enterprise 2012). The gradual appreciation of the Chinese Yuan[3] (CNY) has led to higher buying power for Chinese consumers and attracted more seafood import. The lower trade hurdles set by the Chinese government have also attracted foreign companies exporting seafood into China, and this has helped keep prices down and grow consumption. China's need for grain is expected to increase for at least the next two decades due to increase in population, rising purchase power and the need for animal feeds and possibly bio-fuels (Simelton 2011). For agriculture and aquaculture products, China still registered a trade surplus between 1995 and 2003, but by 2007, the trade deficit for these products had grown to

[3] Annual average exchange rate 1 USD=6.64 CNY (2010), 1USD=6.10 CNY (2013) (source: http://www.oanda.com/)

USD 11.63 billion (Veeck 2008). The average annual growth rate for Chinese seafood imports surpassed that of exports in monetary terms in 1998-2008, which were 17.9% and 14.3%, respectively (FAO 2010). Import values increased from USD 1.8 billion in 2000 to USD 6.2 billion in 2010 and further increased to USD 7.6 billion in 2011, making China the third-largest fisheries products importer in the world (FAO 2012c). The growing domestic demand of China in such markets led to expectations that it would become a net importer of seafood some time in 2011 (Tveteras 2010), raising speculation that global supplies of seafood would become less available and more expensive to other countries (Trushenski *et al.* 2012). China has one fifth of the world population, China's consumption patterns have a major impact on global demand for fish (Blomeyer *et al.* 2012). On the other hand, China may become a market offering great opportunities for the seafood industries in other countries, both for marine farmed fish and fish species not currently used for human consumption (Lindkvist *et al.* 2008).

In this section the development trends of the Chinese aquaculture industry were examined, to find out the reasons for the rapid decline in growth rate of Chinese aquaculture production and the phenomenon of China as a net seafood importer. The main research questions included:

1 Why has the growth rate of Chinese aquaculture production dramatically slowed?

2 Will Chinese aquaculture production show continued growth?

3 Will China become a net seafood importer?

As so successful in Chinese aquaculture industry is, and as China has more experience with aquaculture than any other countries (Hanson *et al.* 2010), these conclusions will be good examples and lessons to other countries that wish to develop aquaculture or seafood export.

3.2. Why fast growth of Chinese aquaculture in 1980s and 1990s?

Historical development in the agriculture sector and increase in food consumption have been largely driven by human population growth, income growth, urbanization, policy, market opportunity, trade liberalisation, trans-national food corporations and improved food retailing (Erenstein 2006; Stentiford *et al.* 2012; Thornton 2010). Rising disposable incomes, urbanisation, improved brand exposure and retail distribution, and changing urban lifestyles are driving major changes in the pattern of Chinese consumer demand (New Zealand Trade and Enterprise 2012).

Aquaculture development is related to factors such as market demand (and competition), the availability of environmental resource, the development or transfer of appropriate technology and a favourable business environment that allows entrepreneurs to profit from their investment in the sector (Bostock *et al.* 2010). The reasons for the fast growth of China's aquaculture in the 1980s and 1990s include the economic reforms that liberated productivity of household enterprises, favourable policies, increasing population, rapid growth of disposable income and soaring market demand. Social changes such as urbanization, and the availability of appropriate technology were also crucial.

3.2.1. Economic reforms and productivity growth

Economic reform gave rise to the leap in China's aquaculture industry through liberating productive forces through a process of market liberalization. After 1978 China's economic policies changed from central planning to a market economy; an enabling environment was created for the aquaculture sector by breaking market monopolies and trade barriers among Chinese regions (FAO 2005; Zhang & Rørtveit 2005). As a result of price deregulation and market liberalization for nonstrategic commodities such as vegetables, fruit, meats, and seafood in 1980s, the price of seafood increased and then provided higher incentives for aquaculture development (Li & Huang, 2005). Land reform initiated in rural China in 1979–85 was another incentive for agriculture and aquaculture development (Li & Huang 2005). In that land reform, the commune system was replaced by the household responsibility system (HRS). Under the HRS, land is contracted to individual households and each household organizes production independently. The decentralization of land use of HRS given more land rights to farmers, which resolved work incentive problems of the collective system, and stimulated farmers' incentives for agricultural production (Dong 1996; Hu 1997; Liu *et al.* 1998; Krusekopf 2002).

3.2.2. Favoured policy

China's fisheries sector once relied on marine fisheries (Chen 2007). Over-exploitation of these resources after the 1970s resulted in obvious decline (Xu & Li, 2008) and a strategy change towards cultured fish production was prioritised in the 1960s, in response to the increasing scarcity of natural stocks and a rising demand for fish (Li & Huang 2005; Zhang & Rørtveit 2005). The dominance of aquaculture was formally established in the first promulgated Fisheries Law in 1986 (Chen 2007; Li 2007). Since 1980s, the general policy for Chinese fisheries has been adjusted to being "*aquaculture oriented*" and towards "*major efforts devoted to aquaculture in freshwater and marine water, protection and reasonable utilization of inshore resources, and active development of mid-water and deep-sea fishery*" (Wang, 2000).

The land policy was not strict in farm land protection before 2000s. A large area of crop land was converted to aquaculture ponds in the Yangtze Delta, for example, with aquaculture increasing from 0.1% to 14.5% of rural area from 1942 to 2002 by converting fallow water surfaces and rice paddies to fish ponds (Wu *et al.* 2009).

3.2.3. Increasing human population, rapid growth of disposable income and soaring market demand

Although family planning measures started in 1980s, the China population still increased quickly into the 1980s and 1990s. The population census shows China's population in 2000 was 1.266 billion, which was 11.66% and 25.56% higher than the population in 1990 and 1982 respectively (NBSC 2012).

In the same period, the national GDP and *per capita* disposable income also increased rapidly. As a symbol of China's economic reform success, economic growth was rapid with average annual GDP growth of about 9.5% throughout the two decades after 1978 (Chow 2004). The *per capita* disposable income also increased rapidly in the same period, more than tripling for urban residents and almost quadrupling for rural residents between 1978 and 1996 (Yao 1999). More than 233 million people were lifted out poverty and the population below the official poverty line reduced from 36% to 2.8% of the rural population between 1978 and 2010 (NBSC 2011a). Increasing population, GDP and *per capita* disposable income led in turn a huge rise in market demand, particularly for high quality food.

Economic development is always accompanied by a food consumption convergence of diets towards westernization. Increased intake of meat, fat, processed foods, sugar and salt are characteristics of this nutrition transition (Kearney 2010). Growth in *per capita* GDP is highly correlated to increased fish consumption in developing countries (Blomeyer *et al.* 2012). There is a growing demand for animal source foods in general, driven partly by population growth but mainly by rising standards of living and prosperity in developing countries (Hall *et al.* 2011). *Per capita* demand for crops, when measured as caloric or protein content of all crops combined, has been a similarly increasing function of *per capita* real incomes since 1960 (Tilman *et al.* 2011). Chinese diets are moving from being dominated by high carbohydrate foods to high fat, energy-dense foods, with more animal products and fewer traditional foods (rice, wheat and vegetables) (Kearney 2010). The dietary trends in China are towards more meat from livestock and fisheries sector and less grain, while grain is fed to animals instead (Simelton 2011). Seafood consumption growth follows the increased spending power and expanded seafood industry in China (Lindkvist *et al.* 2008). Estimated *per capita* seafood supply increased from 4.4 kg in 1972 to 25.1 kg in 1999 in China (FAO 2002b).

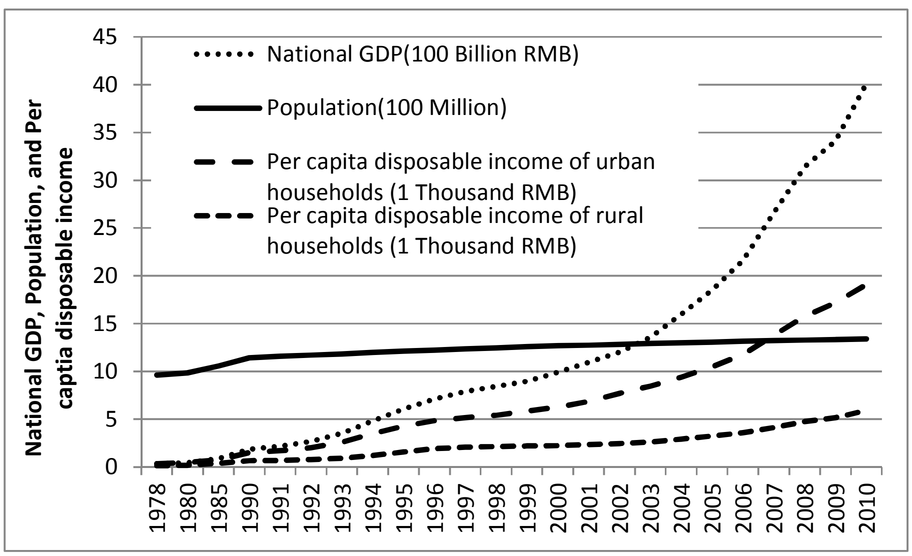


Figure 3.3 National GDP, population, and *Per capita* disposable income

(source: National Bureau of Statistics of China 2012).

3.2.4. Social changes such as urbanization

Urbanization can dramatically change food consumption patterns by improving marketing, better distribution and transportation infrastructure. Modern retailing, especially supermarkets and hypermarkets, and improving access to foreign suppliers are other features (Kearney 2010). The Chinese government has been supporting urbanization for years, in expectation of generating more jobs to absorb the labour freed by modern agriculture and losses in arable land (Wang *et al.* 2012). Urbanisation has occurred in parallel with rapid economic growth in China creating rapid social change. Since 1978, widespread rural–urban migration has occurred supporting economic growth and reducing the rural–urban income gap, urban population increased from 18% in 1978 to 31% in 1999, or from 172 million to 388 million (Zhang & Song 2003). The changed urban lifestyles with better market and distribution systems, higher incomes and increased purchasing power, has led to higher consumption of seafood than in rural areas fuelling market demand. *Per capita* seafood home consumption in urban areas had grown to 10.34 kg by 1999 compared to only, 3.82 kg in rural areas (Lu *et al.* 2002).

3.2.5. Technique availability and development

Technical breakthroughs, especially for breeding carp and shrimp and the development of formulated diets laid foundation for aquaculture development. Although China had a long history of aquaculture, its development had stagnated without the help of modern technology and production had remained low (FAO 2005; Song 1999).

Although aquaculture recovered during 1949-1957 after decades of conflict, two major breakthroughs between 1958-1965, fuelled a major change in the sector. These were the success of artificial propagation for Chinese carps (Hishamunda & Subasinghe 2003) and an improved management framework for carp polycultures based on the theory of "eight words" culture methods: water, seed, feed, density, polyculture, alternate culture, disease prevention and management (Wang, 2000). The artificial breeding of carps and “eight words” methods together shifted China’s aquaculture from an empirical practice to a science-based technology (Li 2003). Since the 1980s, further scientific and technological advancement such as the artificial breeding of many species of seaweeds, molluscs, crustaceans and fish paved the way for large-scale expansion of the Chinese aquaculture industry (FAO 2005). Technology development also made aquaculture intensification possible (Xie *et al.* 2013). As new techniques became available, average yields increased 6.4 times, from 765 kg ha^{-1} in 1980 to 4899 kg ha^{-1} in 2000 (Li 2003)

3.3. Why slower growth rate in 2000s?

3.3.1. Increasing cultures of high-value species

Compared with terrestrial agriculture for which modern development has been focused on a few species targeted with very intense genetic selection to increase the efficiency of production under farm conditions, the aquaculture industry has been based on a large number of genetically undeveloped species (Diana *et al.* 2013). It is likely the range of species cultured will continue to grow; diversification of farming species in aquaculture has been widely advocated (Muir 2005). The farming of ‘high-value species’, which are often carnivorous, has been promoted by industry, governments, scientists and organizations for improving production and profitability (Neori & Nobre 2012), and large-scale aquatic species introduction has characterised the sector globally in recent decades (Gozlan 2008). In the future, it is believed aquatic species will continue to be introduced to exotic environments and reliance on non-native introductions may become a growing reality for aquaculture (Gozlan 2008; Liu & Li 2010; Shelton & Rothbard 2006). However, recently a greater concern for biodiversity and biosecurity might be expected to slow down this process (Adarsha *et al.* 2011; De Silva 2012).

Along with the shifting from a planned to a market economy since the economic reform, seafood was listed as a nonstrategic commodity as part of price deregulation and market liberalization in 1980s (Li & Huang 2005). Since the 1990s, China moved from a focus on increased aquatic food supply to improving fish farmer's income level and living standard. The introduction of many new and high market value species have been part of this (Zhang & Rørtveit 2005). Aquaculture has become more market and profit oriented, and changed from an orientation towards carps to more high value species since 1980. The major reasons for the change were: the saturated market and steady decline in price of carps (Figure 3.4) together with increasing feed costs resulting in lower profit for carp farming. In parallel, more market demand for high value aquatic products along with higher prices and profits (Wu, 2005) underlie these changes that started in the 1980s and became more apparent by the 1990s (Wang, 2000). The trend towards diversification is still one of the major characteristics of Chinese aquaculture (Miao & Liao 2007; Zhou 2007).

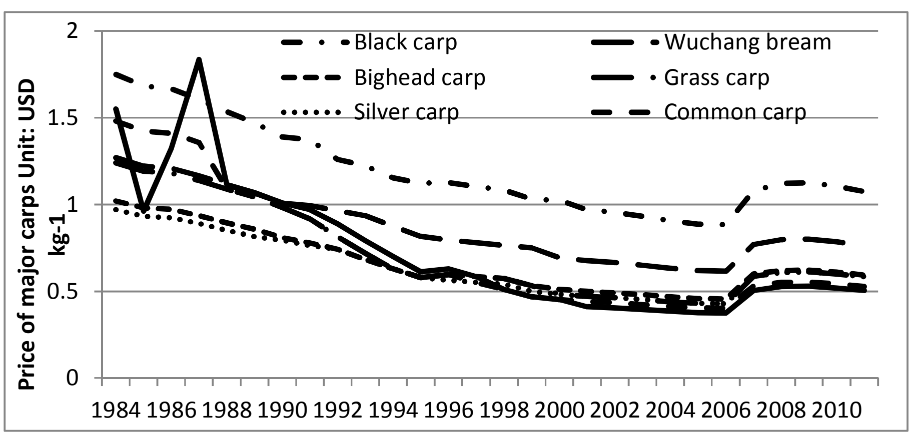


Figure 3.4 Price changes of major farmed carps in China during 1984-2011 (Unit: USD kg^{-1})

(USD values were revised based on buying power changes with 1984 as baseline, source: FAO fishstatJ 2013, www.usinflationcalculator.com)

Aquaculture diversification in China has been affected by geography, the level of local productivity and the propensity for experimentation among Chinese consumers (Mai & Tan 2002). Great efforts were made to diversify aquaculture to more high value species such as mandarin fish (*Siniperca chuatsi*), mitten crabs (*Eriocheir sinensis*) and prawns (*Macrobrachium spp*), soft-shelled turtle (*Trionyx sinensis*), and eel (*Anguilla spp*) in freshwaters, and shrimp, scallops (*Pectinidae*), large yellow croaker (*Larimichthys croceus*), and flounder (*Bothidae* and *Pleuronectidae*) in marine waters (Li 2003). Now China's aquaculture has the largest number of species cultivated (Partners 2010), including high-value exotics such as shrimp and prawns (Liu & Li, 2010), and yields of exotics exceed 25% of the total harvest in China (Shelton & Rothbard 2006). The culture systems for these species has also diversified and aquaculture is recognised as being more dynamic than other food production subsectors in China (Miao 2010).

The long history and dominance of Chinese carp farming (Wang, 2000) is now in flux as the proportion of carps in total production decreased significantly in recent years (Figure 3.5).

However, carps continued their importance for most consumers. A recent fish consumption survey confirmed that carps remain the main stay of rural Chinese diets, particularly in regions where carp is grown (Chiu *et al.* 2013). The rapid expansion of organic aquaculture also gives a new force for carps farming development in the future (Jia *et al.* 2013; Xie *et al.* 2013). Comparing with their substitutes, most carps are low trophic level species, which means they require a low (quantitatively and qualitatively) amount of externally provided protein-rich feed, and carps culture has an environmentally positive meaning (Tacon *et al.* 2009).

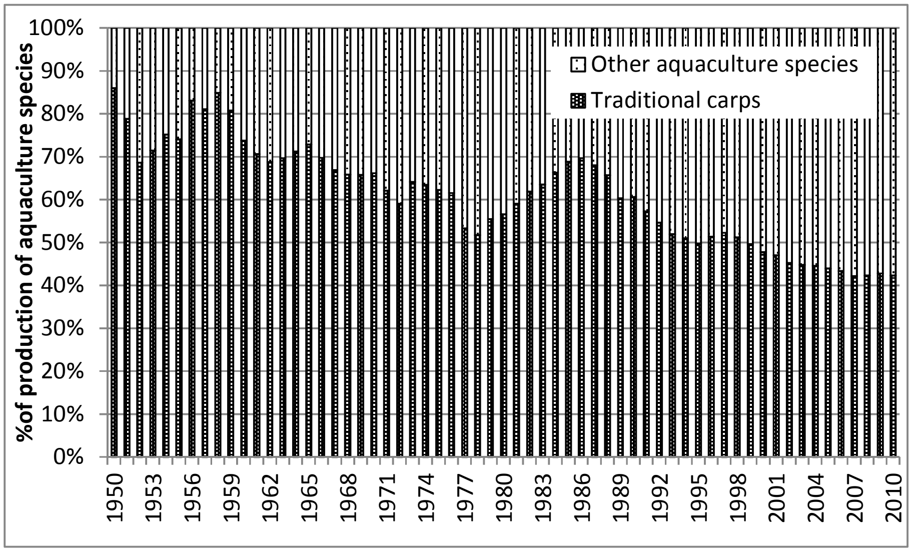


Figure 3.5 proportion of carps production among total aquaculture production in China

(Traditional carps: Bighead carp (*Hypophthalmichthys nobilis*), Black carp (*Mylopharyngodon piceus*), Common carp (*Cyprinus carpio*), Crucian carp (*Carassius carassius*), Grass carp (*Ctenopharyngodon idella*), Silver carp (*Hypophthalmichthys molitrix*), Wuchang bream (*Megalobrama amblycephala*), sources: (FAO 2012a).

As the range of aquaculture species has changed to more high-value species both intensification and extensification have emerged as important strategies. Although some high value species such as snakehead and soft-shell turtle have high yields, many have a very low yields compared to traditional carps (Table 3.1). The high production and low yield implies these species need more farming area than conventional species, which causes high opportunity cost of land and lower overall production growth.

Table 3.1 Some high value species (carps, water plants, mollusks excluded) with low yield (<5 mt ha^{-1}) and high annual production (>100,000 mt) in China

Species (ASFIS)	Environment	Production in 2000 (mt)	Production in 2010 (mt)	Estimated Yield(mt ha^{-1})
Chinese mitten crab	Freshwater	202,489	593,296	~1
Mandarin fish	Freshwater	86,144	252,622	~1.5
Oriental river prawn (*Macrobrachium nipponense*)	Freshwater	87139	225,645	~1
Japanese sea cucumber (*Apostichopus japonicas*)	Marine	No data	130,303	~3
Giant river prawn (*Macrobrachium* rosenbergii)	Freshwater	84,891	125,203	~5
Indo-Pacific swamp crab (*Scylla serrata*)	Marine	No data	115,829	~2

Note: ASFIS - FAO Aquatic Sciences and Fisheries Information System (FAO 2013)

3.3.2. Emerging trends of extensification

Three development pathways for farming systems can be distinguished as extensification, intensification and diversification (Phong *et al.* 2007). The term *'extensification'* has two different meanings: *'the process of making something (more) extensive'*, or *'the geographic spread and distribution of any technology, especially agriculture'*[4]. Agriculture extensification normally means geographic expansion (Phong *et al.* 2007), which is often a rational strategy when sufficient land is available (Erenstein 2006). *'Extensification'* here is used to describe *'the adoption of (more) extensive practices'* in contrast to intensification, and lower inputs and lower yield characterise such systems. This also can be seen as another way of diversification, which can be distinguished from conventional farming system intensification.

[4] http://en.wiktionary.org/wiki/extensification

In China, seafood prices have been declining in recent years and put huge pressure on fish farmers (Xie *et al.* 2013). Following a growing demand for specific attributes of seafood such as healthiness or organic status, farming practices have changed from pursuing high net profits through conventional intensification (i.e increasing stocking densities) to alternative strategies that may result in moderating the intensification process. For example, cost-benefit analysis has demonstrated that Chinese mitten crab farming is much more profitable if lower yields of large sized individuals are harvested rather than high production of small sized crabs (Chen *et al.* 2001). Soft shell turtle produced in very low stocking density, ecological farming systems has a market price two to four times higher than conventionally produced turtles because its attributes are closer to wild soft shell turtle, encouraging the growth of ecological farming in recent years (Ge *et al.* 2013; Liu *et al.* 2007).

Aquaculture certification has started to attract consumers and producers' attention, and more high-value certified seafood been marketed in recent years. High value seafood is not limited to species higher up in the food chain. Bighead carp and silver carp produced in Qiandao lake were certified organic and achieved prices double that of conventional and yet demand could not be satisfied (Jia *et al.* 2013). Organic aquaculture is undergoing explosive expansion in China, mainly driven by domestic market demand, the total production increased 17 times from 5,000 mt in 2003 to 85,000 mt in 2012 (Xie *et al.* 2013). Such organic aquaculture is dominated by large-scale farms and extensive farming systems. The average farm size was 2,299 ha, the average production per farm was 489 mt, and the average yield was only 0.21 mt ha^{-1}, which is much lower than national aquaculture average yield 0.51 mt ha^{-1} (MOA 2012; Xie *et al.* 2013).

The trends of aquaculture extensification are certainly not unique to China but may have different drivers. Along with animal welfare awareness in western countries, lowering aquaculture stocking densities has been associated with improved fish welfare (Turnbull *et al.* 2005). The latest animal welfare certification themes such as Freedom Food already embody the requirement for maximum stocking densities for salmon farming, which is lower than common practiced stocking density (RSPCA 2012).

3.3.3. Environmental degradation, genetic degeneration, and disease outbreaks

Chinese aquaculture faces significant challenges such as deterioration of water quality resulting from eutrophication or water pollution, increases in fish disease that are often linked to declines in water quality, and the degradation of genetic resources due to poor management of domesticated stocks (Liu *et al.* 2007). The negative impacts of environmental degradation, genetic degeneration, and disease outbreaks tend to be inter-connected and difficult to untangle. In 2010, China's aquaculture industry suffered production losses of 1.7 mmt (worth USD 3.3 billion) caused by diseases (295,000 mt), natural disasters (1.2 mmt), and pollution (123,000 mt) (FAO 2012c).

China's aquaculture became more intensified than before principally through the widespread use of commercial pelleted feed (Edwards 2011b). Intensification requires use of external inputs such as feed and fertilizer, that while improving productivity, can have negative environmental effects and increase risk linked to the higher capital investment required, especially for small-scale farms (Murshed-E-Jahan & Pemsl 2011). Frequent occurrences of harmful algal blooms and other forms of eutrophication have become serious issues in China (Xiao *et al.* 2007). Some fisheries are seriously polluted mainly with nitrogen, phosphate, oil and Cu^{2+} by both external and internal pollution sources (MOA 2011c) and environmental degradation is now one of the biggest problems for both aquaculture and capture fisheries. Deterioration of water quality has been linked to outbreaks of disease and economic losses (Hu, 2011). In 2011, it was estimated that there were more than 680 pollution events (from sources external to the fishery) that led to direct economic losses of more than 368 million CNY (MOA 2011c). Environmental change and degeneration caused even higher loss of fisheries resources at 8.426 billion CNY comprising 1.240 billion CNY for freshwater resources and 7.186 billion CNY for marine resources calculated according to volume loss and market price (MOA 2011c).

Genetic degeneration of aquaculture species is another major constraint for China's aquaculture industry. It is reported there was a boom of cross breeding among different common carp geographic populations in 1970s, the hybrids entering the natural environment and causing germplasm mixture and stunted offspring. In the early 1990s the four family carps (black carp, grass carp, silver carp and bighead carp) and Wuchang bream also suffered genetic degeneration caused by poorly managed hatcheries that resulted in inbreeding (Li, 1993). Inbreeding causes loss of valuable genetic diversity and results in negative effects on growth rate, reproductive performance, and survival rate, and more disease and morphological deformities. Over time productivity can be compromised (Hussain & Mazid 1999; McKinna *et al.* 2010; Moss *et al.* 2007; Oss 2008). Around 2000, genetic degeneration was perceived to be common in China's aquaculture species including the four family carps, common carp, mitten crab, soft shell turtle, giant river prawn, large yellow croaker, and shellfish such as bay scallop, oyster and abalone, which not just included native species but also some introduced exotic species (Li, 2001). Genetic degeneration has been identified as an issue for crucian carp (Cheng & Wu 2002), tilapia (Zhou *et al.*, 2007), Chinese limnetic pearl mussels (*Hyriopsis cumingii*) (Zheng *et al.* 2007), sea cucumber

(Liu *et al*. 2007), oriental river prawn (Feng *et al.* 2008), red swamp crawfish (*Procambarus clarkii*) (Jin *et al.* 2011), and whiteleg shrimp (Zhang *et al.* 2012) since 2010. Although awareness of genetic degeneration of aquaculture species is now common, few improved management steps have been implemented. Although genetics research on aquatic animals in China began in the 1980s, most of the animals farmed are still wild stocks, without genetic improvement (Li 2003). According to Hu (2005), among 73 major freshwater aquaculture species, only nine were selected varieties, which included six introduced species, and only three native species common carp, crucian carp and Wuchang bream were selected varieties in China, among 51 major marine culture species, only four were selected varieties, include whiteleg shrimp which was introduced from US (Hu, 2005).

Meanwhile, intensification of aquaculture has led to the management of diseases becoming a primary constraint for aquaculture (Bondad-Reantaso *et al.* 2005) and major sustainability constraint according to the perceptions of a variety of stakeholders (Zhang *et al.*, 2011). In China, for many years the aquaculture industry has pursued a high production and economic return strategy simply through intensification. The resultant deterioration of water quality in turn caused more serious aquaculture diseases (Huang, 2012). Poor seed quality, environment deterioration, lack of health monitoring measures and misuse or abuse of medicines were the main underlying factors behind disease outbreaks (Luo & Li 2010). It is reported that the average losses caused by diseases were higher than 30% in marine culture (Ma & Zhang, 2012). One of the striking examples is the that shrimp disease breakout in 1993 caused large losses and production declines (Qi, 2002). In 2006, statistic shows aquaculture diseases mainly included 11.02% virus diseases, 57.63% bacterial diseases, 24.58% parasitic diseases, and 4.24% fungal disease (Wu & Wang, 2010). In the same year, 180 different diseases were detected in 80 farmed aquatic species and more than 30% farming area was affected by diseases (Chen, 2007). According to available statistics almost all 126 detected diseases had serious impacts and with a tendency away from single pathogen to multiple pathogens and from seasonal epidemics mainly in autumn and spring to year around infections (Huang, 2012). Average annual economic losses caused by diseases have been estimated at more than 10 billion CNY, 55 – 77% from fish species, 11 – 28% from crustaceans and 3 – 16% from shellfish (Wu & Wang, 2010).

3.3.4. Agriculture and environment prioritized over aquaculture

Food self-sufficiency has been a top priority for the Chinese government for decades with a clear policy that it intends to produce 90–95% of its own grain (Simelton 2011). Although China's land mass is very large on an absolute and even *per capita* basis, the proportion of quality arable land is low. A common saying is China is feeding 22% of the world's population with around 9% of the world's arable land (Carter, 2011; Zhou, 2011). In recent years urbanisation has increasingly encroached on arable land (Tan *et al.* 2005). The Chinese central government took serious measures to guarantee grain self-sufficiency and food security after 2000 (Simelton 2011), one of them being a basic farmland protection policy enacted in 2008, aiming to maintain at least 1.8 billion mu[5] of arable land, known as the "1.8 billion mu red line" (Zhou, 2011). Chinese aquaculture production mainly comes from land based ponds (Jia *et al.* 2013), but according to the Regulations on the Protection of Basic Farmland, digging new ponds in basic farmland was strictly prohibited (The State Council 2004). Some news reported local government promoted agricultural land rehabilitation schemes since 2009, included land reclamation from fish pond (Mo 2009; Bai

[5] mu: local area unit. 1 mu = 666.66 m^2, and 1 ha = 15 mu.

2009). It is reported 171 mu area fish pond was rebuilt to farm land just in one village in Guangxi province (Bai 2009). Some fish ponds built by farmer privately without government permission also were reconverted to farmland (Zhao & Fan 2013).

Water stress is one of global development constraints, especially for Asian countries like China (Vörösmarty *et al.* 2000). China is a country that is short of freshwater *per capita* and domestic water shortages have occurred in recent years (NBSO 2010a). Environmental protection has become one of the priorities of central and local governments, and aquaculture has become associated with water pollution (Chen, 2011). Since 2005 aquaculture development has been limited in many lakes, with some existing culture systems being gradually removed (Jia *et al.* 2013). In some important lakes and sensitive water bodies such as the Miyun reservoir in Beijing, Qiandaohu Lake in Zhejiang province and Taihu Lake in Jiangsu province, cage culture and pen culture was prohibited based on the primacy of drinking water source protection and broader environmental protection (Chen 2011; Chen 2012; Sun et al. 2003). In reality aquaculture may often have been a scapegoat for other sources of pollution but having a high profile has been a 'soft target' for regulation. In consequence, the development of freshwater cage farming has been limited, and only accounted for less than 5% of freshwater production in 2011 (MOA 2012).

3.3.5. Labour shortage

Matched with its leading role in global aquaculture and capture fisheries, very large numbers of people (>20million) are dependent on the fisheries sector in China, equivalent to 1.5% of the total population (FAO 2012c; MOA 2012). The overall number of fisheries practitioners (people working in the industry, e.g. works, managers and bosses) for aquaculture and capture fisheries was estimated at 14. 6 million in 2011 (MOA 2012). After the rapid growth of fisheries population and number of fisheries practitioners since the 1980s, the rate of increase in employment in the sector has slowed over the last decade. The number of full-time capture fisheries practitioners stagnated after peaking (1.88 million) in 1998, and the number of part-time fisheries practitioners has reduced substantially since 2000 (Figure 3.6).

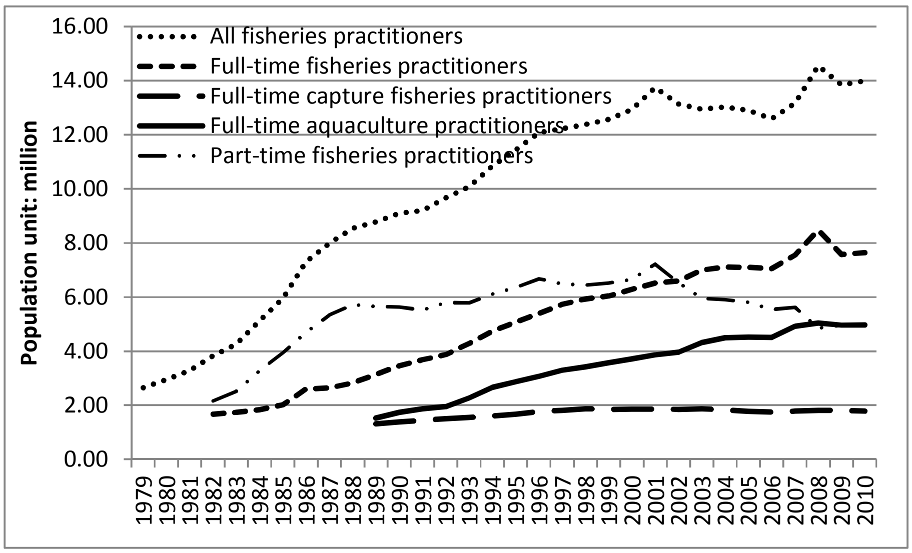


Figure 3.6 Number of fisheries practitioners by full-time and part-time, and by capture fisheries and aquaculture.

Sources: Chinese Fisheries Yearbooks 1980-2011

Another challenge is the rapidly increasing wages due to labour shortages, especially for seafood processing plants. It is estimated the labour cost will increase 120% from 2011 to 2016, mainly because the one-child policy started in 30 years ago has resulted in families wanting their children to attain higher education and white collar occupations. China's working-age population declined for the first time in 2012 causing serious concern that the China's working-age population will continue to decline at least until 2030 (NBSC 2013). This problems is exacerbated by the go-west campaign and development of China’s middle and western areas aiming to restrict labour from migrating to coastal cities where most aquaculture farms and processing plants are located

(Lindkvist *et al.* 2008; Xu 2011).

3.3.6. Climatic variability and natural disasters

In recent years natural disasters became more serious and frequent (Figure 3.7). Most crucial ones including a cold spell in 2008, flooding in 2009 and 2010 and drought in 2011 (Anonymous 2011). It is reported that the cold spell in 2008 led to a total loss of 6.8 billion CNY, some areas lost 90% of their stock of table fish, fingerlings and broodstock (Ou 2008). In Guangdong province alone, cold spell affected areas totalled 17,473 ha, production losses 484,500 mt and the direct economic loss was 6.19 billion CNY (Cai & Liufu 2008). Exotics native to the tropics accounted for most losses, especially tilapia, shrimp and macrobrachium (Cai & Liufu 2008). Floods in Fujian province in 2010 caused by rainstorm destroyed 110,000 cages and damaged 6,667 ha ponds, causing production losses of 60,000 mt and direct economic losses totalling 0.82 billion CNY (Luo *et al.* 2011). The drought in 2011 in the middle and lower reaches of Yangtze river caused an enormous impact on the aquaculture production, according to preliminary statistics the direct economic loss was 9.17 billion CNY over an affected area of more than one million ha (Lv 2011).

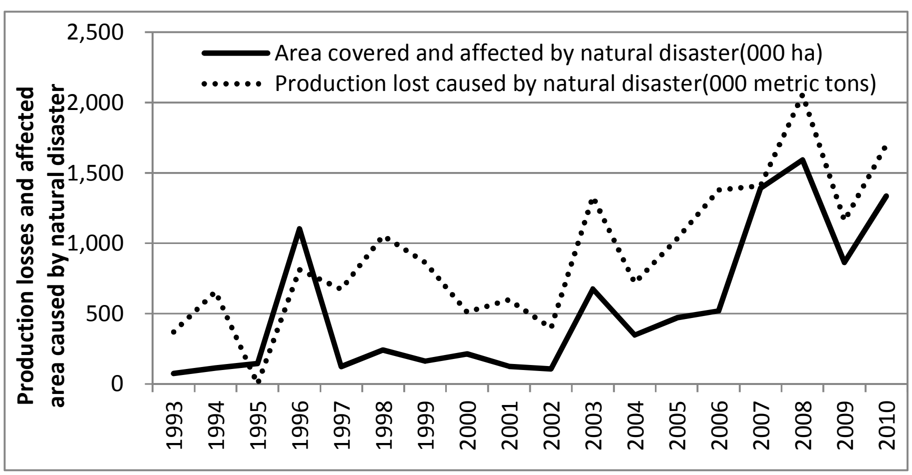


Figure 3.7 Impacts of natural disasters on the aquaculture sector -production losses and affected areas. (Source: MOA 2013)

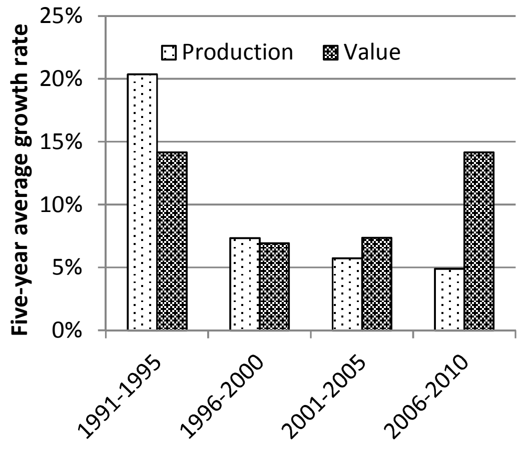
3.4. Strategies behind practice changes

The longer term strategy guiding China's aquaculture industry is to increase productivity in both production and value terms, from simply producing more seafood to higher value and value-added seafood. The strategy also calls for a move from causing environmental damage to ecological remediation, and from producing live fish to marketing value-added products.

3.4.1. Growth in value and higher productivity

In contrast to the major trend of a slowdown in the growth rate of aquaculture production, the growth rate of aquaculture value increased quickly after 2000, which surpassed that of production growth rate and even more than doubled after 2006 (Figure 3.8). These changes in value and production reflect the increased farming of high value species and emerging trends of extensification discussed above.

The increase of productivity and efficiency of aquaculture, rather than simply production increase has been the major focus of government policy in recent years (Bean & Wu 2005). Along with production and value increase, the number of fisheries practitioners stabilised. As a result, *per capita* productivity increased quickly in both production and value terms; and *per capita* productivity in value terms increased even quicker than that of productivity in production term (Figure 3.9). *Per capita* productivity reached 9.6 mt in production term and 12,326 USD in value term in 2010 (Sources: FAO 2014; MOA 2013).



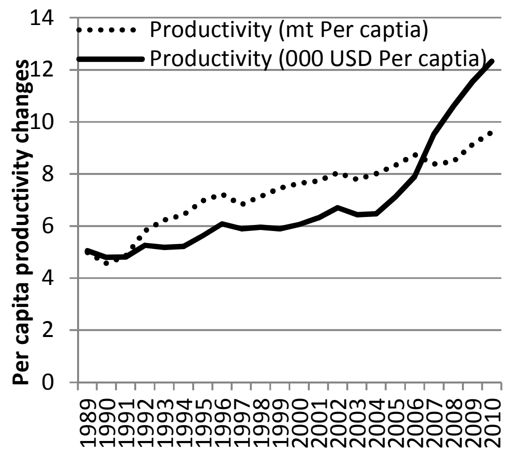


Figure 3.8 Five-year average growth rate of aquaculture production and value in 1991-2010

(Source: FAO 2014)

Figure 3.9 *Per capita* productivity changes in both production term (mt *per capita*) and in value term (000 USD *per capita*) in 1989-2010

(Sources: FAO 2014; MOA 2013)

3.4.2. From causing damage to ecological remediation

It is well known that aquaculture may cause pollution, especially more intensive systems (Pullin *et al.* 1993). Aquaculture not only causes self-pollution, but also has attracted critique and pressure from the public and authorities; the removal of cages and pens from public waters has been a response to this concern. In order to reduce aquaculture pollution, and also resist against pathogens and the degeneration of the environment and genetic stocks, more ecologically balanced culture approaches have been advocated in recent years (MOA 2007). New farming systems and practices keep emerging, including the environmental protection oriented lake fisheries (Jia *et al.* 2013), crab water-plant farming systems (Li & Wang, 2007), upgraded paddy field farming system (Wang, 2011) and integrated multi-trophic aquaculture (IMTA) (Troell *et al.* 2009), although IMTA is mostly in the experimental and pilot stage and its commercial viability remains to be demonstrated in terms of widespread commercialization. These farming systems are not just producing seafood, but also have positive effects on the environment, such as the environmental protection oriented lake fisheries can control and prevent blue-green bloom effectively (Jia *et al.* 2013) while the crab water-plant farming and IMTA systems can improve water quality by uptake and removal of nitrogen and phosphorous from water bodies (Li & Wang, 2007; Troell *et al.*, 2009). Upgrading of paddy field farming system can improve food safety by reducing fertilizer and pesticides used in rice production (Wang 2011; Xie *et al.* 2011). Many aquaculture species have been used for bioremediation, such as bighead and silver carps (Jia *et al.* 2013), seaweeds such as kelp (Troell *et al.* 2009) and bivalves (Li & Wang, 2007). Overall the emphasis has been towards connecting aquaculture to ecological bioremediation, a trend likely increase in the future.

3.4.3. Live fish to value-added products

Seafood processing has developed rapidly as globalization and opportunities in the international seafood trade have emerged. China has gained a reputation for the quality and efficiency of hand filleting compared to competitors and mechanical processing (Blomeyer *et al.* 2012; Lindkvist *et al.* 2008). From 4,255 processors in 1993, the number had more than doubled (9,971) by 2008 before an adjustment during the world financial crisis in 2009 (Beckman *et al.* 2009).

In contrast Chinese consumers prefer live and chilled seafood over frozen seafood, unless some species are not available in the live or chilled forms (Chiu *et al.* 2013; Hanson *et al.* 2010). Chinese consumers believe that the taste of live seafood is better than chilled, and the taste of chilled is better than the frozen (Sun & Che 2012). Most aquaculture products are still sold fresh, only 35%

seafood was processed in China (MOA 2011a), in contrast, more than 70% seafood is processed in developed countries (Bjørn *et al.* 2005). In China most processed seafood is marine, freshwater products were seldom processed because lacking of technology to deal with off-flavour and intramuscular bones (Sun & Che 2012). As Chinese lifestyles become increasingly urbanised and fast paced, especially of high and upper-middle income consumers, packaged and convenience foods have become more popular. The development of supermarkets and hypermarkets has created opportunities for processed food products, as consumers purchase more packaged food infrequently and store food in refrigerators (New Zealand Trade and Enterprise 2012). Increases in absolute population, despite a decline in population growth rate, and increased wealth, higher purchasing power and consumption equates to a greater demand for processed food, meat, dairy, and fish will be needed in the future (Godfray *et al.* 2010).

Volumes of processed seafood increased from 6.5 mmt in 2000 to 16 mmt in 2010 (MOA 2012) but the prediction is 40% of all seafood to be processed by 2015 (MOA 2011a). The development of the processing industry and value-added products is one of the most important targets in the Medium-and Long-Term Fishery Science and Technology Development Plan (2006-2020), also reflected in the 12th 5-Year National Fisheries Development Plans as a national aim (MOA 2011b; MOA 2007).

3.5. Maturity of Chinese aquaculture

In general, the aquaculture industry has been described as 'immature' (Asche *et al.* 2008; Olsen *et al.* 2008) for its environmental impacts (Olsen *et al.* 2008), and for continued reliance of some species on the harvest of wild juveniles rather than hatchery production of domesticated stock

(Asche *et al.* 2008). However, aquaculture in some countries maybe more mature than others. Most mature aquaculture industries include salmon and trout worldwide, oysters, seabass and seabream in Europe, milkfish in the Philippines, and catfish in the US (Partners 2010).

The comparative performance of China's aquaculture, that accounts for more than 60% of world aquaculture production (FAO 2012c), as it develops further can be informed by industry life cycle theory that characterises development into four stages: the introduction, growth, maturity and decline stages (Lipczynski *et al.* 2005). The introduction phase was characterised by high prices and small sales volumes, the growth phase as market expansion and falling prices, the maturity phase as the period when growth of sales and profitability level off and the decline phase as the sales and profits begin to fall (Lipczynski *et al.* 2005). According to this theory, the declining growth rate of China's aquaculture production points to the industry approaching maturity. Maturity assessment tools such as the Fuzzy Industry Maturity Grid contains dimensions which include markets, technologies and industry structure (Tay *et al.* 1992), or in some studies indicators, exclusively economic, have been used to measure maturity (Bhatnagar & Madon 1997; Bock *et al.* 2007). Since sustainability was embedded into the global agenda at the Rio Summit in 1992, Brundtland's (1987, p. 43) '*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*' has become the most widely accepted definition of sustainability (Graymore *et al.* 2009) and sustainability research has become a focus. Sustainable development has later become perceived as a combination of three dimensions or 'pillars', namely, the environmental (ecological), economic, and social dimensions (Lehtonen 2004). In the present study, technique, environmental, economic, and social development dimensions around aquaculture were compared between 1980s/1990s and 2000s in order to explore the maturity level of China's aquaculture (Table 3.2). Key questions related to technical maturity were the status of farming with regard to (1) closing the production cycle i.e. success with artificial breeding and seed production and (2) adoption of intensified farming techniques and use of formulated feeds. With regard to social maturity, the question is: can the industry satisfy seafood demand without import (especially in large countries like China). On an economic basis the major question relates to the outcomes of intensified technology and if it results in maximum profitability. For environmental sustainability maturity questions are: the level of dependence on natural resources (trash fish/fishmeal), the maintenance of appropriate water quality in the culture system itself, and minimal adverse environmental impacts from effluents and exotic species escapes.

Table 3.2 Comparison of aquaculture maturity between 1980s/1990s and 2000s

Categories	Low-level of maturity in 1980s / 1990s	Higher level of maturity in 2000s
Technical maturity	Most farming species not closed farming cycle with succeeded artificial breeding and seed production, formulated pellet feed just started to develop, intensified farming technique not widespread	Most farming species closed farming cycle with few species propagation still not succeeded (Li 2003), formulated pellet feed became available for many species and being widely used, intensified farming technique became widespread
Social maturity	Low production unable to fulfil market demand	High production already can fulfil most market demand
Economic maturity	Few farmers knew intensive aquaculture management skills and practice to produce high-value species	Most farmers now know intensive aquaculture management skills and practice for high-value species
Environmentally sustainable maturity	Awareness of environmental impacts before 1980s were low	Increasing environmental awareness although few farmers try to improve their environmental performance – major issue to be resolved

Comparison of technical maturity, social maturity, economic maturity and environmentally sustainable maturity shows low-level of maturity in the 1980s and 1990s and higher level of maturity in 2000s although yet to reach full maturity. For technical aspects, a few species are still dependent on wild juveniles such as Japanese eel (*Anguilla japonica*) and longjaw grenadier anchovy (*Coilia macrognathos*), and many species are still fed trash fish and other unprocessed raw materials such as wheat bran with very low efficiency (Mai 2010a). For economic maturity, farmers' profits have been adversely affected by over production and competition. The environment will be the major focus for resolution in the future.

3.6. Seafood consumption

Seafood consumption has increased quickly from a very low base number (Figure 3.10); *per capita* seafood consumption was 15.19 kg in urban areas and 5.36 kg in rural areas, the national average was only 10.53 kg in 2012 (NSBC 2013). These figures are undoubtedly affected by the consumer's preference for live fish, making transportation difficult and the supply period short (Bean & Wu 2006). Seafood supply tends to be locally sourced (Chiu *et al.* 2013).

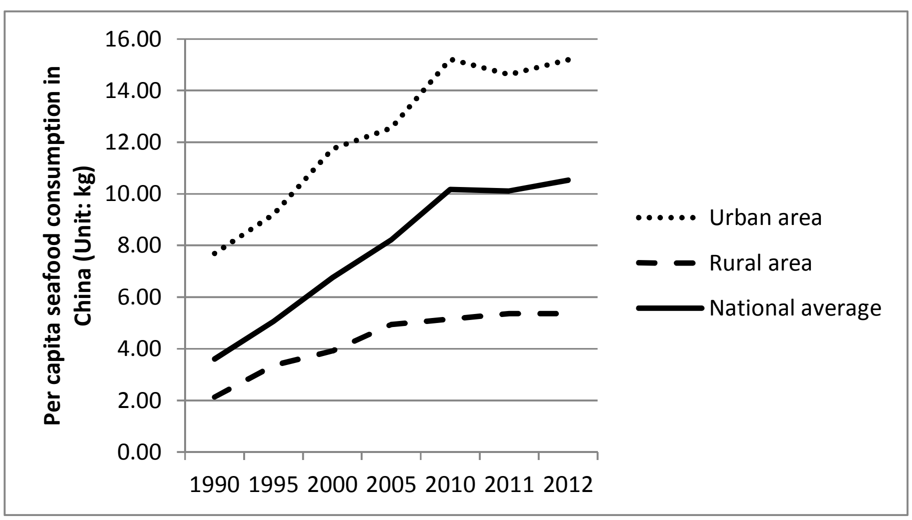


Figure 3.10 China *per capita* seafood consumption in rural and urban area and national average

(Source: NSBC 2013)

Lack of consistent terminology by the aquaculture academic community has led to misunderstanding. For example the confusion of the concepts seafood consumption and seafood supply, or the common interchangeability of the terms ‘fish’ and ‘seafood’. The frequent under reporting of catches by China’s distant-water fishing fleet was related to inaccurate seafood consumption data in China (Blomeyer *et al.* 2012; Villasante *et al.* 2013). Until recently many studies reported China’s *per capita* seafood consumption at a much higher level, such as 29 kg or 35 kg (Blomeyer *et al.* 2012; Delgado *et al.* 2003; Glitnir 2006; Villasante *et al.* 2013), most of such numbers were originally cited from FAO biennial SOFIA reports, and followed mistakes made by FAO who mixed up seafood consumption and seafood supply in the first place. In SOFIA (2008), it was stated that “*China…reported fisheries production of 51.5 million tonnes in 2006, providing an estimated domestic food supply of 29.4 kg per capita*” (FAO 2009b), which is contradicted with the SOFIA 2012 stated “*…per capita fish consumption in China…reaching about 31.9 kg in 2009*” (FAO 2012c). Chiu *et al.* (2013) examined China’s seafood consumption by field survey, and confirmed the official seafood consumption data reported by National Statistical Bureau of China (NSBC) was correct; however, the NSBC data only included home-consumption; out-of-home consumption contributed a 2 – 3.5 kg *per capita* and 2.7 – 4.7 mmt for the country as a whole (Chiu *et al.* 2013). The total seafood consumption was around 14.24 mmt according to NSBC or around 17 – 19 mmt according to Chiu *et al.* (2013), all of which are much lower than total seafood supply, which was 59 mmt in 2012 (Chiu et al. 2013; MOA 2013; NSBC 2013), which implies a large proportion of seafood was not destined for direct human consumption. The proportion of fisheries products as processed and non-processed products destined for food service (restaurants and catering) and retail (‘home consumption’) or for use as an industrial raw materials is not well understood. Some studies show a large difference (more than 40% Lu, 1998) in seafood production and consumption data. Two seafood consumption studies show around 64% seafood was consumed as food in China, with industrial extraction emerging as a major use only in the latest study (Table 3.3). Sun & Che (2005) reported total seafood consumption as 40.26 mmt in 2003, which is much lower than the reported annual production of 47.06 mmt (Sun & Che 2005). Since the national agriculture census in 2007, FAO and Chinese government have amended historical fisheries statistics for 1997-2006 (FAO 2012c), the revised annual production in 2003 is 40.77 mmt (MOA 2012), and very close to Sun & Che's total consumption data.

Table 3.3 Comparison between two China's seafood consumption studies

Consumption category		1994 (Li, 1996)		2003 (Sun & Che 2005)	
		Raw material equivalent volume (mmt)	%	Raw material equivalent volume (mmt)	%
Total seafood consumption		27.6	100%	40.27	100%
Consumed as food	Total	17.85	64.67%	25.89	64.29%
	Home consumption*	6.85	24.82%		
	Processing	6.2	22.46%		
	Restaurant	3.4	12.32%		
	Catering	1.4	5.07%		
Export		1.7	6.16%	2.63	6.53%
Industrial extraction		2.85	10.33%	7.05	17.51%
Transportation loss		1.2	4.35%	4.7	11.67%
Trash fish in aquaculture		2.4	8.70%		
Gift		1.6	5.80%		

* Home consumption = total production – (processed +consumed outside the home [e.g. restaurant] + transport loss + export) + import (source: (Li, 1996; Sun & Che, 2005)

A frequently quoted projection of Chinese 35.9 kg *per capita* seafood consumption by 2020 originated from Delgado *et al.*, (2003) article which has been then been cited by many other studies (Blomeyer *et al.* 2012; Chiu *et al.* 2013; Glitnir 2006; Nie 2006). Such projection also mixed seafood consumption and seafood supply.

3.7. Seafood export and import

Both exports and imports only account for only a small proportion of total fisheries production in China, most of which is consumed domestically. China became the world's biggest fisheries product exporter in 2002, and accounted for 12% world fisheries products exported by value in 2010 (FAO 2012c). The growing importance of China as an exporter and a value-added re-exporter is a clear trend (Washington & Ababouch 2011) supported by the reduction in its tariff rate on fish products from 47.2% to 9.5% after joining the World Trade Organization (WTO) (Dey *et al.*, 2005; Xiao, 2007). The establishment of the China-ASEAN (Association of Southeast Asian Nations) Free Trade Zone, bilateral trade agreements such the China-Chile Free Trade Zone as well as those currently under negotiation with Australia, New Zealand and Iceland are expected to further accelerate seafood trade (Xiao, 2007). The growth of China's seafood in the international market benefited from China's low labour costs and the predominance and quality of hand processing (Clarke 2009). FAO (2010) expects these advantages to grow as international trade restrictions are further reduced. Although fishery exports only account for 1% of Chinese export value they exceeded that of all other agriculture products by 2009 (MOA 2010a; NBSC 2011a), and accounted for nearly 30% of total agriculture product export value in 2011 (Yu, 2012).

China has become a net importer of fishery products in volume terms since 1984 (Figure 3.11) which is mainly explained by its soaring demand for fishmeal and its status as a major processor. In 2011, the total import volume was 4.25 mmt, compared to 3.91 mmt exported. However, China still has a huge trade surplus in monetary terms with export value of 17.7 billion USD compared to an import value of 8.02 billion USD (MOA 2012). The differences in trade volume and value is explained by the low cost of raw material imports and value-added export products.

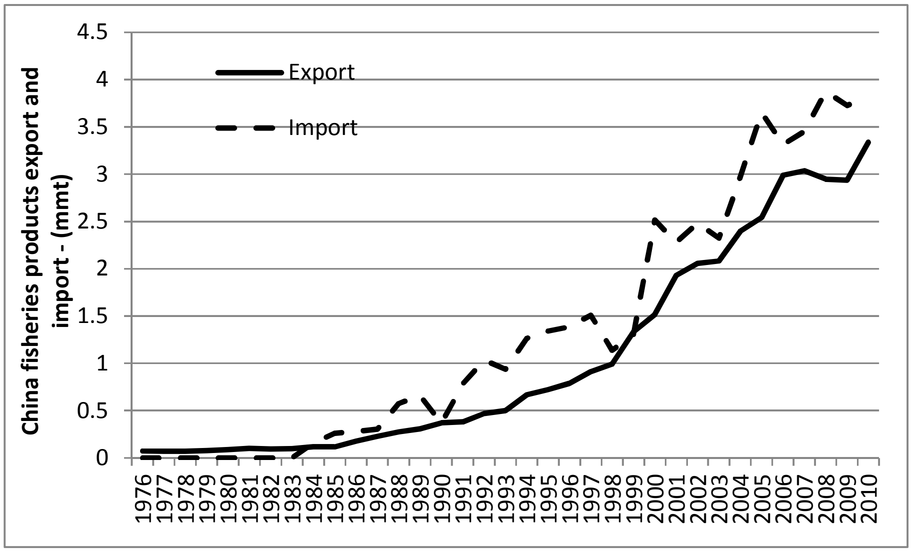


Figure 3.11 China's fisheries products export and import since 1984

(Source: FAO 2014; China Customs 2014)

The Chinese fisheries export trade can be divided into two different categories, general trade and processing trade (Table 3.4). The general trade mainly exports aquatic products from which the raw material originates inside China. The processing trade is mainly based on imported raw materials that are then exported. It is reported such processed products accounted for more than 30% of export value in 2011. Processed fish fillets account for 60% of export value of the processing trade (Yu, 2012). However, the proportion of re-exported products (processing trade) in the total export reduced in recent years (Table 3.4). Exported seafood is mainly farmed species, of which a few categories dominate namely shrimp, shellfish, tilapia, eel, large yellow croaker, red swamp crayfish and channel catfish, these categories accounted for 50.15% of total seafood export value in 2011 (Yu, 2012).

Table 3.4 Fisheries products export value (billion USD) and volume (mmt) by different category

Year	Export					
	Total		General trade		Processing trade	
	Value	Volume	Value	Volume	Value	Volume
2000	3.83	1.53				
2001	4.19	1.95	2.54	1.33	1.56	0.55
2002	4.69	2.09	2.79	1.40	1.70	0.57
2003	5.23	1.98	3.28	1.31	1.95	0.67
2004	6.97	2.42	4.07	1.48	2.59	0.80
2005	7.89	2.57	5.05	1.66	2.84	0.91
2006	9.36	3.02	5.92	1.97	3.44	1.05
2007	9.74	3.06	5.95	1.97	3.79	1.10
2008	10.61	2.96	6.66	1.89	3.95	1.08
2009	10.70	2.94	6.92	1.96	3.78	0.98
2010	13.83	3.34	9.42	2.24	4.41	1.10
2011	17.79	3.91	12.46	2.70	5.33	1.21

Source:(MOA 2004a; MOA 2005; Mu 2007; Ma 2008; MOA 2010a; Yu 2012; Xiao 2002; Xiao 2003)

In recent years, the volume of fisheries products imported by China increased significantly. This can be explained by several factors, including increased domestic market demand for species not available from local sources in addition to the demands of the processing industry for re-exporting stimulated by lower import duties following China's accession to the WTO (FAO 2012c). The import value increased from USD 1.8 billion in 2000 to USD 6.2 billion in 2010 and further increased to USD 7.6 billion in 2011, making China the third-largest fisheries products importer in the world (FAO 2012c).

The Chinese fisheries import trade can be divided by three different categories, which are general trade, processing trade, and fishmeal trade. The general trade mainly imports aquatic products for domestic consumption or for ornamental purpose. The processing trade is sourcing raw materials used for re-export. The raw material used for re-export comes from all major fisheries regions, including South and North America and Europe (FAO 2012c). The major importing countries in 2009 included Russia, Peru, United States, Chile and ASEAN (MOA 2010a). Although re-export used to be more significant than import, the fisheries products imported for domestic consumption (categorized as general trade) increased very fast, from 0.51 mmt in 2000 to 1.52 mmt in 2011 (Table 3.5). Imported seafood is mainly wild species, with fishmeal being the most important category and much of it destined for aquafeeds in recent years (Chen, 2012). Fishmeal has become the biggest single fisheries product imported in recent years and although volumes have stagnated and the value increased rapidly, which attracted much of attention in line with global competition for this limited source (Reuters 2013; Jackson 2012; Chiu *et al.* 2013).

Table 3.5 Fisheries products import value (Billion USD) and volume (mmt) by different categories

Year	Import							
	Total		General trade		Processing trade		Fishmeal	
	Value	Volume	Value	Volume	Value	Volume	Value	Volume
2000	1.85	2.52		0.51		0.82		1.19
2001	1.88	2.31		0.48		0.93		0.90
2002	2.27	2.49		0.60		0.94		0.96
2003	2.48	2.33		0.48		1.05		0.80
2004	3.23	2.99		0.56		1.30		1.12
2005	4.12	3.66		0.65		1.43		1.58
2006	4.30	3.32		0.71		1.64		0.98
2007	4.72	3.46		0.86		1.64	1.01	0.97
2008	5.40	3.88	1.70	1.13	2.31	1.41	1.40	1.35
2009	5.26	3.74	1.73	1.14	2.23	1.29	1.30	1.31
2010	6.54	3.82	2.42	1.49	2.44	1.30	1.66	1.04
2011	8.02	4.25	2.98	1.52	3.28	1.52	1.75	1.21

Source: (MOA 2004a; MOA 2005; Mu 2007; Ma 2008; MOA 2010a; Yu 2012; Xiao 2002; Xiao 2003)

3.8. Research questions and scenarios

The development of scenarios around a consistent set of assumptions is a frequently chosen approach that goes beyond a single projection and presents the user with several possible future trajectories (Lutz & Samir 2010). Scenarios are powerful tools to cope with uncertainty, test hypotheses and explore the future (Reilly & Willenbockel 2010), and have been used in large scientific ventures to address problems such as climate change or global ecosystem health (Winowiecki *et al.* 2011). Scenarios are used as a powerful experiential learning tools rather than predictions (Reilly & Willenbockel 2010).

In this study three scenarios were deployed in order to test hypotheses based on the following research questions. Scenario 1 used a variable growth rate hypothesis to address the question why the growth rate of Chinese aquaculture production has decreased. Scenario 2 used future consumption potential to answer the question 'Will Chinese aquaculture production continue to increase?' Scenario 3 used linear regression models to answer the question 'Will China develop into a net seafood exporter or importer?'

3.8.1. Scenario 1 – Variable growth rates

The average annual growth rate of Chinese aquaculture decreased from 12% in 1980s and 13.6% in 1990s to 5.5% in 2000s and 5.6% in 2010 (FAO 2012a). Since 2000, if the sector had retained its growth rate of 1980s and 1990s, increasing by 13%, what would production have been in 2010? Further, what are the outcomes if this growth rate (13%) or that of the 2000s (5.5%) could be maintained, on production levels in 2050?

According to calculation, with a 13% growth rate the total production in 2010 will be 96.6 mmt, while the total actual production was 47.8 mmt (Figure 3.12). Aquaculture production in 2050 would be 413 mmt with 5.5% growth rate and 12,828 mmt with 13% growth rate (Figure 3.13).

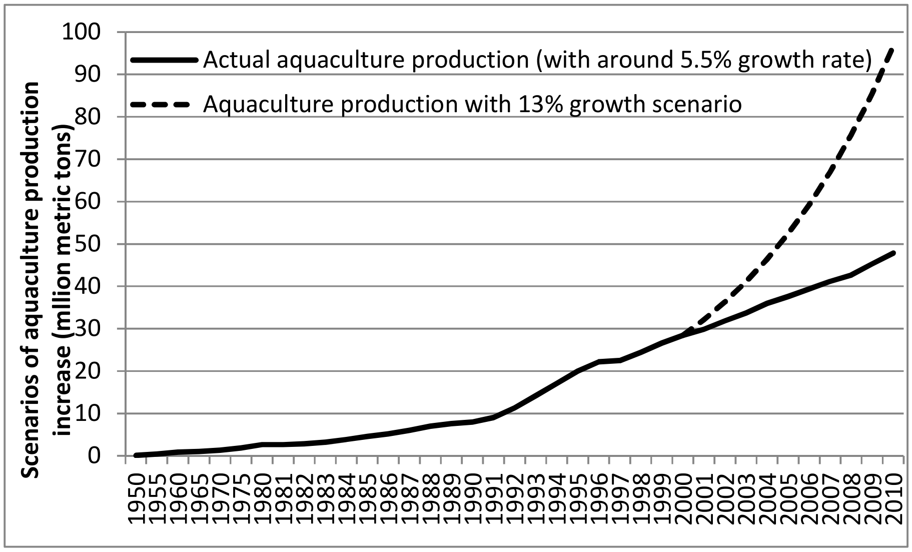


Figure 3.12 Scenario of aquaculture production to 2010

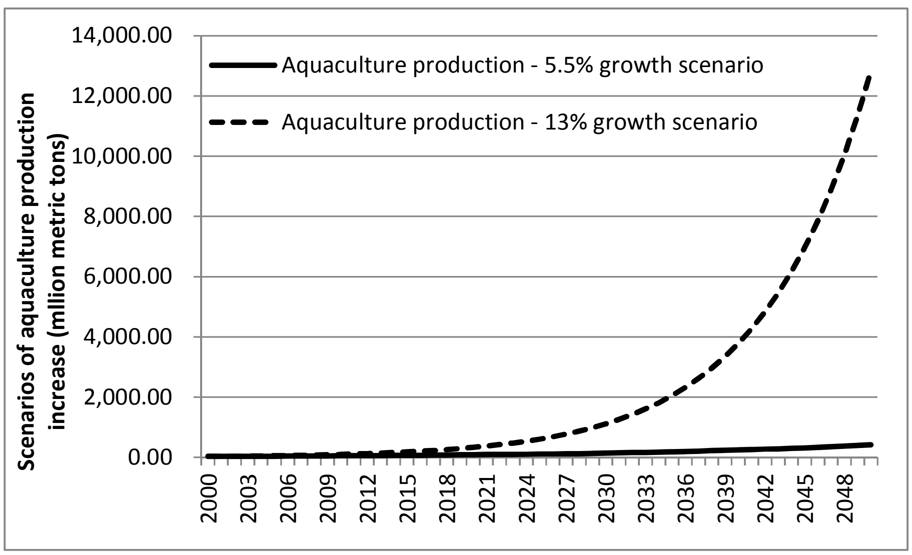


Figure 3.13 Scenarios of aquaculture production to 2050

A major conclusion based on the scenarios is that growth in total Chinese aquaculture production has been large even though annual growth rate has decreased. Maintaining a high growth rate is not necessary, realistic or sustainable. Growth rate is a not a useful statistic as even a small growth rate leads to a huge increase in absolute production with a large base number. This is demonstrated by human population growth rates that although starting to decline more than 50 years ago still resulted 50% increase in a global population by 2010 (United Nations 2013b).

3.8.2. Scenario 2 – Future increase in production

Economic development is not balanced throughout China, the east and coastal areas are the most prosperous areas with the highest seafood consumption. When mean wealth reaches the level attained in most developed areas such as Shanghai, how much seafood would be needed? According to statistics, *per capita* seafood consumption in Shanghai was 18.5 kg in 2010 (NSBC 2013), which was 80% more than the national average. This suggests that there is still huge potential for a further production increase based on likely increases in demand.

How many years would be needed for fisheries production to increase 80% more than the national average since 2010? Based on stagnated status of capture fisheries, production of capture fishery will most likely remain stable, and fisheries production growth will come from aquaculture. Aquaculture will need to increase from 38.29 mmt in 2010 to 81.27 mmt in the future to fulfil 80% increase of total fisheries production. Thus the question becomes how many years is it likely to take for aquaculture production to increase from 38.29 mmt to 81.27 mmt? As predicted by MOA, the average aquaculture growth rate will be 4% in 2011-2015 (MOA 2011b). Assuming an aquaculture growth rate since 2010 remains 5.5% (growth rate in 2000s), or 4% as MOA predicted. Since 1990 the annual absolute production growth became stable and linear, a linear regression model was developed based on production from 1990 to 2010 as: $Y = 6.721 + 1.939 * X$, $R^2 = 99.8\%$ (SPSS19). Based on three different growth rates, 5.5 %, 4% and the linear regression model, the fisheries production will accomplish the target of 80% increase in 2023 with fixed 5.5% growth rate, in 2028 with fixed 4% growth rate, and in 2036 according to the linear regression model (Figure 3.14).

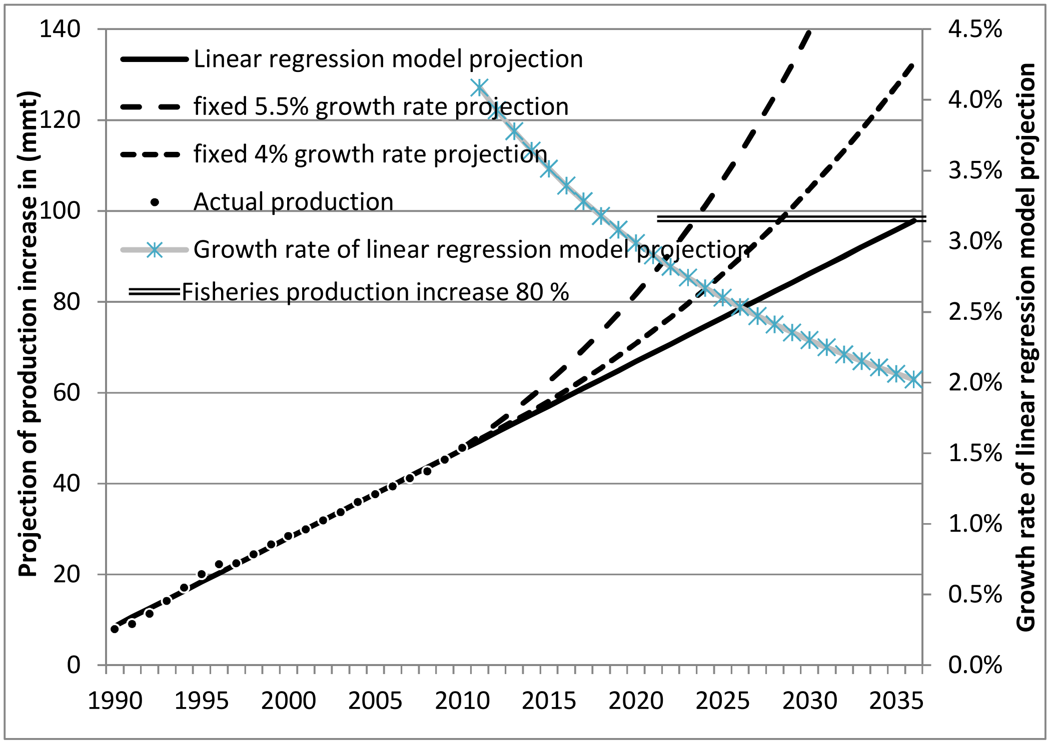


Figure 3.14 Scenario of aquaculture production increase (mmt)

Scenario 2 shows China's aquaculture would need to maintain growth in the future in order to meet the huge potential market demand. The high value of R^2 (99.8%) suggested high reliability of linear regression model. According the linear regression model, the aquaculture growth rate in 2011-2015 would be around 4% as MOA predicted, but tends to drop off over time. The linear increase of the aquaculture production with a declining growth rate reveals the increasing base number of total production and the stable net annual growth volume becoming relatively smaller than earlier years. Aquaculture production would increase from 38.29 mmt in 2010 to 81.27 mmt in 2036 to fulfil 80% increase of total fisheries production according to the linear regression model.

3.8.3. Scenario 3 – Net exporter or importer

As described above, China is a net importer of seafood, but only if fishmeal is included. Since 1990 the growth in export and import volumes has stabilised and two linear regression models were built, based export and import volume from 1990 to 2009. Export linear regression model is Y=-0.138+0.164*X, R^2=96.7% (SPSS19), and import linear regression model is: Y=0.199+0.179*X, R^2=93% (SPSS19). According to linear regression models, China will continue to be a net fisheries product importer.

However, the statues of China is being a net aquatic product importer mainly due to huge volume fishmeal import (Ma, 2008; MoA, 2004, 2005, 2010; Mu, 2007; Xiao, 2002, 2003; Yu, 2012). As the global production of fish meal has reached a plateau (FAO 2012c), it will not be possible for China to continue to increase its imports into the future. Processing waste has become another important raw material source for fishmeal: an estimated 36% of global fishmeal was produced from processing waste in 2010 (FAO 2012c). In China, fishmeal production from processing waste surpassed that from capture fisheries since 2006 (FAO 2012c) and further utilization of processing waste has the potential to meet future needs for fishmeal rather than reliance on imports. With fishmeal excluded, the actual export volume is higher than import. Based on the fishmeal excluded export and import data from 1990 to 2010, the export linear regression model is Y=-0.138+0.163*X, R^2=96.7% (SPSS19), and import linear regression model is: Y=-0.211+0.136*X, R^2=94.5% (SPSS19). The trend lines base on the linear regression models shows with fishmeal excluded, China will continue to be a net exporter of aquatic products (Figure 3.15).

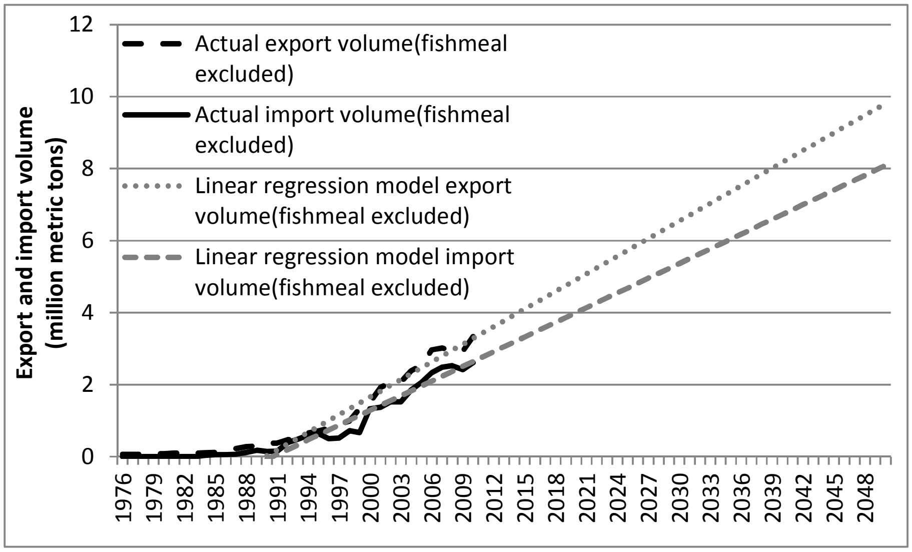


Figure 3.15 Projection of China's fisheries products export and import volume (with fishmeal excluded)

3.9. Why Chinese Aquaculture will continue to grow?

The future market demand growth and improving productivity will guarantee the future of China's aquaculture growth. Aquaculture growth was believed to be affected primarily by resource drivers such as availability of space and feed; attitudinal drivers such as public and consumer attitudes, legislation, etc.; and innovation drivers such as new technology and market developments (Olsen *et al.* 2008). According to Huang *et al.* (1999), the industry growth drivers could be divided as consumption drivers and production drivers or demand shifter and supply shifter. Aquaculture development also was driven by both consumer demand in domestic and international market, and farmers and entrepreneurs seeking profit (Edwards 2011a). It is reported that China's agriculture growth has been mainly driven by consumption drivers such as population increase, income growth and urbanization, and production drivers such as institutional change, investment in technology and income supports and market reform (Huang *et al.* 2010).

3.9.1. Consumption side drivers

For a healthy diet, the recommended seafood intake is at 50 g day^{-1} or 2–3 servings $week^{-1}$ (Olsen *et al.* 2008), which is equivalent to 18.25 kg $year^{-1}$. The average *per capita* seafood consumption in China was only 10.53 kg in 2012 (NSBC 2013) or around 13 – 14.5 kg with out-of-home consumption included (Chiu *et al.* 2013), which leaves significant potential for seafood consumption to expand to reach the recommended intake level. China Food and Nutrition Development Program (2014-2020) issued by the State Council declared the development goals of *per capita* annual food consumption by 2020, which include 18 kg of seafood (State Council 2014). To accomplish this goal, the seafood supply for direct consumption needs to increase sharply from now to 2020.

Rapid economic growth and a slow population growth in China means seafood demand increases will mainly be driven by growth in household disposable income (Partners 2010). The remarkable economic growth after economic reform with average growth rate of *per capita* GDP around 8.6% over the 30-year period 1978–2007 was seen as unprecedented (Ding & Knight 2011). However, as one of the fastest-growing economies, China's economic growth will eventually slowdown (Eichengreen *et al.* 2012). Along with the economic crisis in the western countries, China may also not be able to maintain the high economic growth rate in the future as it depends a lot on exports to the West. China's economic growth is expected to slow down in the near future (Eichengreen *et al.* 2012; Lee & Hong 2012; United Nations 2013a) but the economy will continue to grow (United Nations 2013a). The former chairman Jintao Hu reported on the opening of the 18th National Congress of the Communist Party of China (CPC) on 8th November 2012 that Chinese GDP, as well as *per capita* incomes of urban and rural residents will be doubled in 2020 compared to 2010

(XinHua Net 2012), means the annual growth rate higher than 7% in the period 2010-2020. The World Bank (2012) also reported China's GDP will keep growing, providing steady reforms and no major shocks occur (Table 3.6). China will become the biggest economy by, or even before, 2030 with the rise of the middle class and fast pace towards urbanization, the consumption share in the total GDP will increase from less than 50% in 1995-2010 to more than 65% in 2030 (World Bank 2012). It's estimated that the Chinese middle class will increase from 90 million in 2005 to 650 million in 2015 (Glitnir 2006), increasing disposable income leading to more expenditure on food such as meat and seafood (Cirera & Masset 2010). China's urban population has already (2011) surpassed its rural population (NBSC 2012), and this trend will increase such that by 2025 urban areas will be home to 822 million people from the 607 million at present (New Zealand Trade and Enterprise 2012). China has 13 million upper-middle-class households with annual incomes between CNY 100,000 and 200,000, the equivalent of USD 15,000 to 30,000, and will increase to 76 million households by 2015 (Atsmon *et al.* 2011). The upper-middle income population in China can afford to pay higher prices for food and they are motivated to do so because of increasing concerns about food safety and health (New Zealand Trade and Enterprise 2012). The study also shows urbanization and following factors such as increasing income, changing the diet structure and habit, better logistics and distribution system will increase market demand for seafood (Zhou, 2008). The continuing urbanization, increasing buying power and market demand will be a precondition for China's Aquaculture production increase.

Table 3.6 Projected China's GDP growth rate and consumption share in the total GDP.

Period	GDP Growth rate	Share of consumption
1995-2010	9.9%	48.6%
2011-2015	8.6%	56%
2016-2020	7%	60%
2021-2025	5.9%	63%
2026-2030	5%	66%

Source: (World Bank 2012)

In contrast to the projections for economic growth, there is less agreement of China's population growth. The Research Report on National Population Development Strategy published by a government-backed research group in 2007 predicted the population will be 1.36 billion in 2010, 1.45 billion in 2020 and to peak at 1.5 billion by 2033 (National Population Development Strategy Research 2007). But this prediction was proven wrong, with sixth national census shows the population was only 1.34 billion in 2010 (NBSC 2011b), which similar to 1.341 billion in 2010 reported by the United Nations (United Nations 2012). According to latest World Population Prospects, the Chinese population will peak at 1.387 billion in 2020 and will then decline such that the projected population in 2050 will be similar to, or even lower than, the actual population in 2010 (United Nations 2012).

Although China's major media considers the one-child policy as a great triumph, successfully preventing 400 million births over the last three decades (National Population Development Strategy Research 2007), it has stimulated many debates and criticisms. In 2012, for the first time China's working-age population (3.45 million; National Bureau of Statistics of China 2013) has declined, and the debate about the one-child policy has emerged in China (Lu, 2012). At the Third Plenary Session of the 18th Central Committee of the Communist Party of China on November 12, 2013, the *"Decision of the CCCPC on Some Major Issues Concerning Comprehensively Deepening the Reform"* was adopted and then published, in which one of major reform was on the one-child policy. A new policy will be initiated nationally in 2014 allowing married couples to have two children if one of the parents is a single child, and gradually adjust and improve the birth policy to promote balanced population growth in the long run (CCCPC 2013). For the huge suppression effect of the one-child policy and Chinese traditional beliefs of "more children bring more happiness", it is certainly the population will continue to increase along with the one-child policy being adjusted. The population increase was seen as a key driver of seafood demand and fisheries development (Garcia & Rosenberg 2010), and future population increase in China also need more seafood.

At the same time, many studies in developed countries show increasing in age is positively related to increasing in seafood consumption, but no clear quantitative data were given how much increase in percentage (Myrland *et al.* 2000; Olsen 2003; Trondsen *et al.* 2004; Verbeke & Vackier 2005). Along with demographic change towards an aging population in China, which was greatly accelerated by population control (NBSC 2011b), its effect on seafood consumption remains unclear and needs further study.

3.9.2. Producer side drivers

China's aquaculture has become more intensified than before (MOA 2012). The average yields of both freshwater and marine culture continue to increase; marine culture has higher yields than freshwater, mainly due to high yields of offshore seaweed culture. Among freshwater culture, pond farming systems have the highest yields at 7 mt ha^{-1}, which is much higher than lake and reservoir farming systems at 1.5 mt ha^{-1} (Figure 3.16). Since 2007, after a joint FAO/MOA agricultural census, Chinese aquaculture production data in 1996-2007 was re-evaluated (FAO 2012c; MOA 2012). However, the amended farming area data were not published so in order to analyse the intensification trends we have adjusted results from 1996 to 2007 with revised farming area estimates, using the published adjustment coefficient for total production. Although the trend is clear, data inconsistencies result in a significant fluctuation in average yield data around 2007 (Figure 3.16).

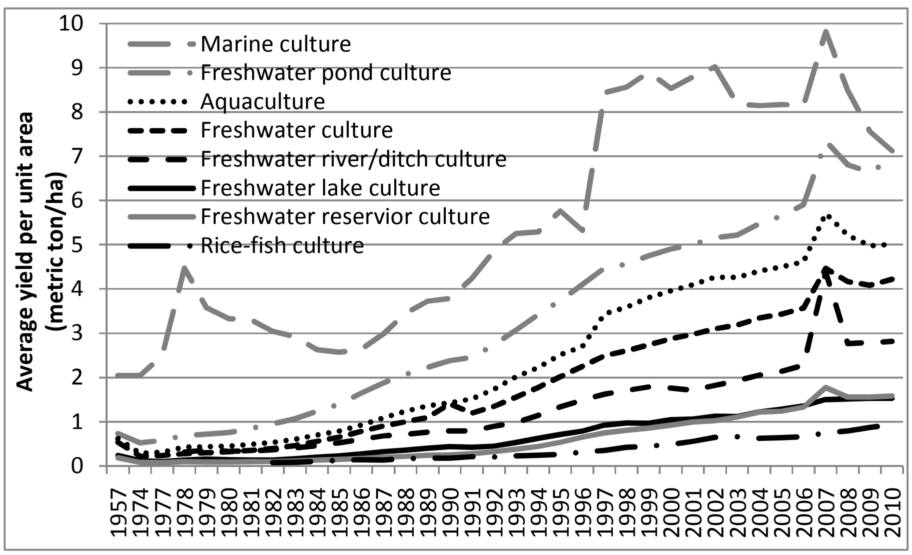


Figure 3.16 Corrected aquaculture intensification trends in China (Source: MOA 2012).

Secondary data show aquaculture areas in all different type water bodies have increased since 1970s, except for the river/ditch culture that has decreased and reservoir culture and lake culture that have increased only slowly (Figure 3.17). Marine culture and freshwater pond aquaculture accounted for most production, the trends of fastest expansion have been for the marine culture area and the freshwater pond culture area. Trends show the marine culture area and freshwater pond culture area will continue to increase in the future, and will contribute to further aquaculture production increase.

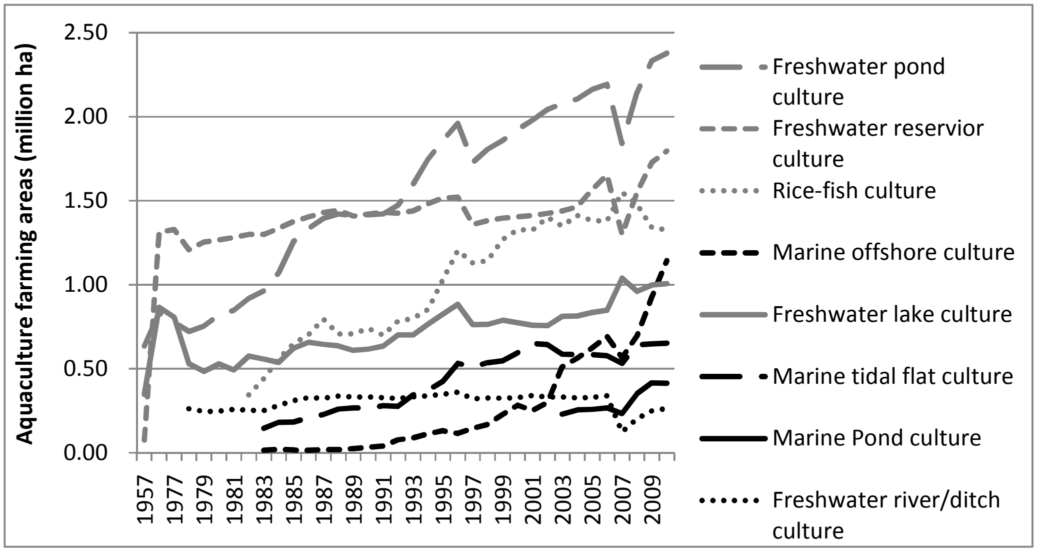


Figure 3.17 Aquaculture farming areas in different type water bodies in China

(Source: MOA 1978; MOA 1980; MOA 1982; MOA 1984; MOA 1986; MOA 1988; MOA 1990; MOA 1992; MOA 1994; MOA 1996; MOA 1998; MOA 2000; MOA 2002; MOA 2004; MOA 2006; MOA 2008; MOA 2010; MOA 2012; MOA 2013) (Note: Aquaculture farming areas in 1997-2006 were adjusted proportionally according the census result and production data revisions by MOA in 2007)

However, the aquaculture area expansion is facing obstacles, the utilization rate of aquaculture in different types of water body is already high (Table 3.7).

Table 3.7 Utilization rate of different type water bodies for aquaculture in China.

	Total water area (Ha)	Aquaculture area in 2011 (Ha) (MOA 2012)	Utilization rate
Shallow sea (<15m) / intertidal zone	13,300,000 (MOA 2006b)	2,106,380	15.84%
Freshwater pond	2,000,000(Wang, 2000)	2,449,910	122.50%*
Freshwater lake	8,351,500 (An *et al.* 2008)	1,023,010	12.25%
Freshwater reservoir	2,285,000 (An *et al.* 2008)	1,851,880	81.05%
Freshwater river/ditch	8,207,000 (An *et al.* 2008)	272,680	3.32%
Paddy field	30,057,000 (NBSC 2012)	1,207,910	4.03%

*The reason for the utilization rate is higher than 100%, is the difference between an earlier baseline from a reference published in 2000 and the utilization area from another much later reference published in 2012. (sources: (MOA 2006b; An et al. 2008; NBSC 2012; MOA 2012))

For marine culture, it is reported along the national costal line almost all intertidal zone and water body inside the 15 m depth contour are fully utilized for aquaculture purpose (Li *et al.* 2006), but some study shows marine culture still has huge potential to expand, especially in the area between 15 m and 40 m depth contour (MOA 2006b). For freshwater pond culture, the utilization rate higher than 100% is because the difference between an earlier baseline from a reference published in 2000 and the utilization area from another much later reference published in 2012, and also reveals the rapid expansion since 2000 and the importance of pond culture. Although new pond construction in farmland was strictly prohibited by the Regulations on the Protection of Basic Farmland (The State Council 2004), there are many areas of uncultivated wild land. One survey shows China has around 26,800,000 ha uncultivated wild land, in which around 16,080,000 ha has potential to be reclaimed (Kou *et al.* 2008), some of it as aquaculture ponds. For freshwater lake culture, the real utilization rate is higher than reported, for the statistic data did not include resources enhancement and releasing and ranching, which was conducted in most lakes except for lakes in sparsely populated regions (Jia *et al.* 2013). Freshwater reservoir culture already has high utilization rate; moreover, in the recent years lake and reservoir culture was restricted by the government (Jia *et al.* 2013) and unlikely have to have potential for further expansion. Freshwater river/ditches maintain a low utilization rate in recent decades and did not share the pace of aquaculture expansion, mainly because the high risk of disease and their greater exposure to pollution and extreme weather (Chen & Chen, 2011). Although rice-fish culture increased fast, the utilization rate was only 4.03% in 2011. Study shows the development of rice-fish farming is no easy task, requiring not only an appropriate agro-ecological context and adequate farmers' education and training, but also participatory extension and research approaches for sustainable agriculture strategies such as integrated pest management (Bosma *et al.* 2012). FAO reported that China's rice-fish system has utilized 15% of the suitable rice area, and thus still has considerable scope for expansion (FAO 2012c). In future, the aquaculture area still has potential to expand, especially for developing new pond in uncultivated wild land area, shallow sea culture and rice fish system. In contrast, freshwater lakes, reservoir and river/ditch culture are unlikely to expand further.

Genetic improvement which had revolutionized livestock and poultry industry has only just begun for aquatic animals (Fitzsimmons 2011b; Gjedrem *et al.* 2012). Research on several aquaculture species in developed countries shows the genetic gain obtained for growth rate was five to six times higher than what has been achieved in terrestrial farm animals (Gjedrem 2012). Animals selected for faster growth have also been shown to have improved feed conversion and higher survival, implying that increased use of selectively bred stocks leads to better utilization of limited resources such as feed, labour, water, and available land and sea areas (Gjedrem *et al.* 2012). Limits imposed by the availability of feed resources would be lessened by growing more herbivorous species and by using more of genetically improved stocks (Gjedrem *et al.* 2012). The success of genetic improvement in salmonid and tilapias is expected to be replicated with other aquaculture species (Gjedrem 2012; Gjedrem *et al.* 2012), and the potential for productivity gain of aquaculture species genetic improvement could be considerable scope for further development (Muir 2005).

Although genetic gains are significant for aquatic species, less than 10% of global aquaculture production is based on genetically improved stocks at present (Gjedrem *et al.* 2012). The paucity of improved varieties was believed to be a major constraint to China's aquaculture development during a crucial stage in its evolution from traditional farming to modern industry (Gui & Zhu 2012). In response to the perceived poor seed quality, various government initiatives have been launched to develop and disseminate improved certified varieties. Central and local governments have invested 1.6 billion CNY to improve capacity for improvement in seed quality. This included funding 17 aquatic genetic breeding centers, 63 national broodstock centres, 65 aquatic aboriginal and improved seed farms, and more than 400 provincial aquatic conservation and improved seed farm. Further expansion was planned, including three aquatic seed quality testing centres by the end of 2010 (Wei *et al.* 2012). A focus on selecting aquatic varieties of the currently produced aquaculture species (100+) including freshwater and marine water fish, shrimp, shellfish by the National Certification Committee of Aquatic and Bred Varieties (NCCAV) and certification by the MOA as high quality seeds for nationwide promotion (Jiang & Ming 2012). Up to 2010, the penetration of improved varieties in the aquaculture industry was estimated at 55% (MOA 2011b). Progress has been made to disseminate improved varieties by nearly three billion fry and over 60 million fingerlings of improved varieties of common carp, crucian carp and silver carp and were distributed nationally under the National Technology System for Conventional Freshwater Fish Industries programme (Wei & Zhang, 2012). Adoption of improved techniques could accelerate this improvement of broodstock such as the latest genetic techniques using within-family marker-assisted selection, which are more effective and quicker than traditional methods (Sonesson 2007). Genome technologies are already applied to breeding programs and genetic improvement of salmon, trout, tilapia and catfish. Ongoing genetic research in genome technologies of aquaculture species such as somatic cell nuclear transfer and stem cell technologies have begun to enter a new era for molecular design breeding (Gui & Zhu 2012).

Improved feeds and feed management are the main factors required to sustain aquaculture production in Asia (De Silva & Hasan 2007). Nutrition research and improving feed efficiency is another positive factor for China's aquaculture. Compared with it's thousand year history in aquaculture, China's aquafeeds industry has only developed in recent decades (Mai 2010a), starting in the late 1970s and expanding rapidly since the late 1980s. It has since become the fastest expanding agricultural industry in China (Miao & Liao 2007) with production increasing from 0.75 mmt in 1991 to 12.75 mmt in 2008 (Mai, 2010b).

Not all aquaculture species need feed input but it is reported that around 40 – 45% of farmed fish in China are now fed on pelleted feed (Miao & Liao 2007), or around 15.7 mmt aquaculture production was dependent on feed in 2010 (Tang 2012). Homemade feeds using ingredients such as wheat bran, rice bran and soybean cake still contribute; an estimated 3 – 4 mmt trash fish and 30 – 40 mmt of other feed raw materials such as wheat and rice bran and soybean cake are still used annually (Mai, 2010a, 2010b). The low efficiency of such feeds, (FCRs tend to be high) because the ingredients are less well processed, pellets less water stable and formulations less optimal, is balanced by their lower costs. Although Miao & Liao (2007) reported farm-made feeds remain important for some species, the latest study shows a very low proportion (3%) of farm made feed still being used in tilapia and shrimp farms in China (see Chapter 5). However, it is believed the feed efficiency will be improved further as formulated diets are improved (Tang 2012). Significant feed inputs are imported (soybean, fishmeal, fish oil) and their price on the world market is likely to rise (Partners 2010). Although fishmeal and fish oil used in aquaculture was seen as a net loss of protein for human consumption, they will not be a constraint for aquaculture development due to alternatives being available (Naylor *et al.*, 2000; Naylor *et al.*, 2009)

New technology in the future could have huge potential effects on the aquaculture industry. At a higher level of technical sophistication, the use of transgenic techniques, and the potential for increased growth, environmental tolerance or disease resistance, could result in significant change (Muir 2005). Aquaculture is in a continual change to intensification, mainly due to high market demand and new farming technologies such as genetic selection, feed formulation, and water quality management (Diana *et al.* 2013). One of the classic examples of new technology having changed the aquaculture industry is the use of vaccines by the Norwegian salmon industry in the early 1990s, which reduced most antibiotic use and increased salmon production rapidly (Alderman & Hastings 1998; Asche *et al.* 1999). New aquaculture systems such as deep-water cages, industrial aquaculture and integrated multi-trophic aquaculture (IMTA) have been developed in recent decades. Industrial aquaculture (flow- through) and RAS was seen as the best solutions for aquaculture to minimize environmental impact. Industrial aquaculture began in the 1990s and developed quickly after 2000, reaching a culture area exceeding 3,000,000 m^2 RAS culture area is around 50,000 m^2 (Wang & Cui, 2009). However, survey shows industrial aquaculture and RAS consumed ten times more energy than pond culture per kg fish produced (Che *et al.* 2010). Industrial flow-through systems pump ground water, which is not just energy consuming but can also cause serious environmental problems such as eutrophication, disease transmission and ground water depletion (Wang & Cui, 2009).

The co-culture of seaweed and shellfish farming along the coastline, is traditional but the rapid uptake of fin fish cage culture and impacts of terrestrial sewage are both having destabilising effects (Ferreira *et al.* 2008). Coined as IMTA in recent decades in the international literature, these are established systems in China that remain largely research and development activities elsewhere (Troell *et al.* 2009). Scope for further and sustainable expansion in China will require governance that apportions value to such aquaculture in the face of other resource users in the coastal zone.

3.9.3. Potential drivers

Further reforms are major potential drivers for China's economy as well as aquaculture development. The World Bank predicted China's future GDP growth also based on the precondition of steady reforms and no major shocks (World Bank 2012). Policy reforms in education, property rights, and research and development can substantially raise GDP growth in the region and partly offset the slowdown in growth (Lee & Hong 2012). Land reform is likely to be particularly important for future aquaculture development. For historical reasons land rights remain obscure with rights for the trade or transfer unclear and little evidence for any consolidation of aquaculture farms. The new land reform started from 2008, based on the household contract responsibility system to develop the land transfer and trade system and encourage large-scale operations through farmers' cooperatives (Baidu Net 2013). The "Land Administration Law" was reported as a mechanism for implementing land reform (Yang, 2012), underpinned by the belief that such new land reform could further emancipate productive forces (Baidu Net 2013) and stimulate aquaculture development. The *"Decision of the CCCPC on Some Major Issues Concerning Comprehensively Deepening the Reform"* were essentially "guidelines" to a new wave of reforms started at the end of 2013, although the planning and implementation of all reforms require more time.

Another potential driver is the extended usage of aquatic products for renewable energy and in industry. The alternative energy resources and biofuel research has become more important than ever because of its potential to fill fossil fuel shortages in the future. Whilst the green credentials of conventional biofuels based on cereal products such as maize and corn have been criticized (Ulgiati 2001), algae, both macro- and micro-, could be suitable alternatives on account of their capability for accumulating high starch and cellulose without competing with food crops for land and freshwater (John *et al.* 2011; Um & Kim 2009). Algae biofuel producing research also started in China in recent years and is believed to have a prosperous future (Yang *et al.*, 2012). Microalgae biofuel research was listed as a key research field in the China's "*Twelfth Five-Year Plan for Biological Technology*" as an important carbon fixation tool (Ministry of Science and Technology 2011). Algae as a sources of polymers, hydrocolloids, ulvan, pharmaceuticals and cosmetics, high value oils, and colorants is also promising (Carlsson *et al.* 2007). Algae farming has great potential when biofuel technology will become more economically viable in the future or the demand for it as industry material sources become bigger.

More sophisticated techniques such as GMOs, artificial meat, and even the nano science and nanotechnology, are all potential "game changers" and very promising for future food production, although certain ethical issues should be addressed before any wide ranging application (McHugh 2010; Sozer & Kokini 2009). All these new technologies could be potential drivers for future aquaculture development.

3.10. Discussion

3.10.1. Data accuracy

In this study many secondary data were collected, analysed and applied as the main part of the evidence, FAO was the most important data source. However, FAO data have been criticized for its low reliability and accuracy. One example is the mixed seafood consumption and seafood supply data discussed above. All food policy analysts at the global level have to use national-level data from FAO, which in turn are based on submissions from national statistical agencies (Delgado *et al.* 2002). FAO's Fishstat was seen as too unreliable with a mixture of catch over-reporting by a few countries, and serious under-reporting by most others, notably developing countries (Pauly & Froese 2012). Fishermen throughout the world tend to under-report catches, and some governments, particularly in countries where administrative advancement depends on production levels claimed, tend to over-report them (Delgado *et al.* 2002). Blomeyer *et al.*, (2012) observed that China did not have reliable estimates of its fisheries catch due to the highly de-centralised fisheries management system and the small-scale of its coastal vessels. China's fisheries production data had been criticized by Watson, who claimed fisheries data in Chinese statistics submitted to and published by FAO led to *"systematic distortions in world fisheries catch trends"* as a paper published in Nature (Watson & Pauly 2001). The questioning of China's aquaculture and fisheries production data is not new inside China. Some studies published in Chinese journals show there was a data gap between seafood production and consumption, with differences potentially being more than 40% (Lu 1998), however, an incomplete understanding of seafood consumption channels could also partly explain the data gap. Another study in 2003 showed that total seafood consumption was 40.26 mmt, which is much lower than the reported annual production 47.06 mmt (Sun & Che 2005).

FAO responded to Waton's Nature paper in its own website, declaring that FAO has been concerned about China's agriculture and fisheries statistics for years and had been working with

China to rectify the deficiencies; quote: "*the problem is therefore known and action is being taken on it*" and "*despite likely errors in the data sets, the main global trends have not been masked, and the most important conclusions have emerged*" (FAO 2002a). It is reported FAO and Chinese fisheries authorities conducted a joint national agriculture census in 2007 and recalculated the fisheries production data based on the census data (FAO 2012c). It was also explained in the China fisheries yearbook, how all production data had been revised based on field survey and random sampling (MOA 2010b). Since the national agriculture census in 2007, the FAO and Chinese government have amended historical fisheries statistics for 1997-2005 (FAO 2012c), the revised annual production in 2003 became 40.77 mmt (MOA 2012), very close to Sun & Che's total consumption data 40.26 mmt in 2003 (Sun & Che 2005), implying that the data reliability had improved.

In this study, we are fully aware of the dangers of using any secondary data which is not subject to strict review. For example, we found the almost identical annual growth rates for capture and aquaculture in the 40 years from the 1960s to 2000s rather suspicious (Figure 3.1). We have tried to assess data for trends instead of providing a static picture, which is more easily affected by deviations of data sets. Furthermore, we have used triangulation methods such as analysis of secondary data from different sources combined with a review of multiple sources including Chinese language and grey literature.

3.10.2. Uncertainty

There is little doubt that aquaculture production will continue to grow (Asche *et al.* 2008). All forward projections anticipate a need for increased supply of fish protein to meet the health needs and general aspirations of societies (Bostock *et al.* 2010). However, the future is always full of uncertainties, for example, the total world population prediction by 2050 varies from eight to 10 billion due to unknown future fertility and mortality trends in different parts of the world (Lutz & Samir 2010). In 2004, UN predicted the world population will peak at 9.22 billion in 2075 (UN 2004). However, the world population growth also is slowing down. The latest prediction shows the world population will peak at 8.7 billion in 2055 and then decline to eight billion by 2100 (Moodley 2013). Many studies related to future development of aquaculture production have been published in recent years, the projected annual world aquaculture growth varied from 0.4% to 5.3% (Blinch *et al.* 2011; Brugère & Ridler 2004; Cochrane *et al.* 2009; Costa-Pierce *et al.* 2011; Frid & Paramor 2012; Olsen *et al.* 2008).

The common knowledge that marine capture has reached its limit in growth (De Silva 2012; FAO 2012c; Garcia & Rosenberg 2010; Robards & Greenberg 2007; Olsen *et al.* 2008) has its critics, even though the assumption that capture fisheries will maintain the current level of production were a precondition of all three scenarios in the present study. It is reported climate change is expected to decrease marine capture fisheries production in China, and Chinese aquaculture industry will therefore need to produce more seafood to meet demand (Merino *et al.* 2012). On another side, a recent study shows that mesopelagic fish, which live at depths between 100 and 1,000m, constitute 95% of the world's fish biomass and are untouched by fishing yet (Prigg 2014), implies there is still huge potential for further growth of capture fisheries.

Complex socio-ecological systems such as the food system, have been seen as unpredictable, especially to long-term horizons (Reilly & Willenbockel 2010). All future estimations are actually more like advanced guesses (Olsen *et al.* 2008). Future demand for food could be heavily moderated by socioeconomic factors such as human health concerns, and changing socio-cultural values (Thornton 2010). Technological surprises like the 'green revolution' would have been very difficult to predict using prior historical data (Reilly & Willenbockel 2010). Future food production will increasingly be affected by competition for natural resources, particularly land and water, competition between food and feed, climate change and carbon constraints, environmental and animal welfare legislations, and novel technologies such as nanotechnology and artificial meat (Thornton 2010).

Global environmental and socioeconomic changes are happening simultaneously, and they involve rapid and complex processes with uncertain consequences (Ericksen 2008). Future development is much more complicated than a mathematical or economic question; it cannot be resolved by any indicator or model, idealized and simplified from real world situations. Only 'fully probabilistic' projections can avoid uncertainties (Lutz & Samir 2010). Uncertainties in assessment include technical, methodological, and epistemological uncertainties, an accumulation of which makes assigning probabilities to outcomes challenging (Reilly & Willenbockel 2010).

Although future demands and production predictions are limited by many uncertainties, they are strategically important for thinking about the social, economic, and technological factors that may affect the realization of those predictions (Olsen *et al.* 2008). One 'best-guess' forecast is valuable and sufficient for many purposes (Lutz & Samir 2010). Such evaluations, often termed as foresight studies, may be more important than the predictions themselves (Olsen *et al.* 2008).

Estimates of world fisheries production need to be consistent with the best available economic data drawn from a wide variety of independent sources, including trade statistics on fish and fish feeds, micro-studies on fish-feed use and aquaculture production, and household studies of fish consumption (Delgado *et al.* 2002). The future development of global aquaculture doesn't just depend on future technologies, but rather public demand, markets, and commitment to its future success (Nash 2011). Future aquaculture production could be affected by changes in capture fishery, and changes in population, income distribution, *per capita* fish consumption and consumption preferences, and price competitiveness of aquaculture products (Muir 2005).

In China, the biggest source of uncertainty regarding seafood consumption at present is the high risk financial market, as BBC economics editor Robert Peston described the eye-popping loan growth figures and the coming collapse of China economy similar with other bubble bursts (Peston 2014). However, this was challenged by Eamonn Fingleton, a former editor for Forbes and the Financial Times, who believes it’s just kind upside-down propaganda manipulated by Beijing to convince western countries that China’s rise is somehow an illusion (Fingleton 2014). The future of the overall Chinese economy seems blurred and there are a lot of discussion and controversy about which there’s a lot of debate and controversy which is beyond the scope of the present thesis.

Logistic improvement could be another uncertainty in China aquaculture development. There remains a tradition of marketing fish live, with the result that the greatest volumes of fish are traded through local food and seafood markets supports a myriad of small wholesalers and retailers; it was estimated that 58% aquatic products were still distributed by sole traders as recently as 2006 (Zhou *et al.* 2008). Live fish transportation makes maintaining health and quality a challenge, especially as cold chain facilities have been unsophisticated, more than 15% seafood were estimated to be lost during transport for such reasons (Hu & Yang 2011). It is estimated that only 23% of aquatic products was transported by cold chain as frozen product and 40% as chilled product in 2010 (Hu & Yang, 2011). But the situation is now changing rapidly, especially in the coastal cities as supermarkets begin to dominate retail. Although live fish is sold in supermarkets, processed product is becoming more acceptable, and high value, imported, frozen seafood is becoming more available and desired. Cold chain development is now perceived to be important as the solution to seasonal and geographical mismatches in supply and demand (Hu & Yang 2011). Logistics improvement promoted by foreign and domestic supermarket chains, and fast developing national infrastructure made access to seafood easier, particularly in remote areas (New Zealand Trade and Enterprise 2012). New cooling and freezing based distribution channels will increase the demand for processed seafood and also redirect more of the catches currently used to feed fish in aquaculture into consumption markets (Lindkvist *et al.* 2008). Improved logistics systems can reduce the high percentage lost during transport, and can reduce market demand for aquaculture, but also can increase seafood consumption in rural area. However, a recent national wide survey shows live fish and local food markets still dominated as retail outlets, accounting for 58%–82% of seafood consumed (Chiu *et al.* 2013). The logistic system improvement and how much the tradition of live fish eating can be reserved in the future thus is a big uncertainty in aquaculture development.

Besides production increase, it was argued that China can increase seafood supply by redirecting some exports to the domestic market, or by relocation of its aquaculture grow-out farms in other countries, such as in Africa or Latin America, a similar strategy to the relocation of other types of China’s food production to other countries (Partners 2010). Shifting from the export market to domestic market has already happened for channel catfish (*Ictalurus punctatus*), which was exported to the US in large volume before 2010, whereas now almost all is sold in domestic market, mainly caused by competition from Vietnamese striped catfish and higher price in the domestic market (Cui & Xiao 2012; Yan *et al.* 2013).

3.10.3. World wide applications

Future projections of exponential growth of the sector have been downgraded in this study that shows the aquaculture growth is more likely to be linear with stable net annual growth volume and decreasing growth rate. Initial phases of industry development often went through a very rapid growth (Partners 2010), as the starting part of a boom-and-bust cycle (Asche *et al.* 2008). The early high growth rates can be explained by low production level, for example, highest aquaculture growth in 2007 was Lesotho (6450%), Rwanda (909.5%) and Ukraine (590.8%) (Bostock *et al.* 2010). Smaller percentage growth in countries with already substantial production has a greater impact, for example, 5.2% growth in China represented 52.3% of the total increase in global aquaculture supply for 2007 (Bostock *et al.* 2010). Similarly, the growth rate of global agricultural products has been slow, with an average annual growth rate around 3% in the 1960s to only 1.8% in the 1990s, and around 1.4% during 1970-2000 (Shelton & Rothbard 2006). The world aquaculture growth rate also declined from an average annual rate of 10.8% in the 1980s and 9.5% in the 1990s to 6.3% in the 2000s (FAO 2012c).

Comparing the fast aquaculture development in developing countries, especially in Asia, the average annual growth rate of aquaculture in developed countries was much lower, only 2.1% in 1990s, declining to 1.5% in the 2000s (FAO 2012c). Major aquaculture developed countries such as Japan, the United States of America, Spain, France, UK, Canada and Italy almost all plateaued, except for Norway that still demonstrated growth of its salmon industry (FAO 2012c; Bostock *et al.* 2010).

The slow growth, high technical level and high productivity of aquaculture in developed countries are indicators of the mature status of these industries (Partners 2010). Slower growth was also blamed on labour conflicts and the stringent regulation and legislation, especially that related to environmental protection and international competition. Aquaculture growth in US, for example, has been slowed down by government's weak advocacy, strict, complex aquaculture and environmental regulations, and opposition from various stakeholder groups (Chu *et al.* 2010; Knapp 2012; Wirth & Luzar 2001). Marine culture has been totally banned in the State of Alaska (Knapp 2012). In Europe, annual growth of aquaculture has declined to 1%, partly because of market factors such as increased international competition, but also because the industry is subject to stringent regulation and sustainable development is a major consideration (CBI 2011; Nunes *et al.* 2011).

The low cost and low price seafood from Asian countries is more competitive, although it's based on lack of stringent environmental regulations and inexpensive labour costs (Chu *et al.* 2010; Nunes *et al.* 2011). Total fisheries and aquaculture production in developed countries even decreased 10% in the period 2000–2010 (FAO 2012c). However, the seafood consumption does not decrease, despite the decline in fisheries production mainly due to substitution by imports, especially from developing countries (FAO 2012c). It is believed the seafood international trade will continue to increase in the future due to sustained demand, trade liberalization policies, globalization of food systems, technological innovations, improvements in processing, packaging and transportation as well as changes in distribution and marketing (FAO 2012c). However, the seafood production growth rate is less than that of seafood consumption in developing countries, implying decreasing net exports of seafood from the developing to the developed countries, driven by increasing domestic demand in the former (Delgado *et al.* 2002), which makes the future seafood supply to developed countries more risky and the voice of promoting aquaculture in developed countries likely to strengthen (Little *et al.* 2012; Little *et al.* 2008).

In contrast to the general trend of aquaculture shifting from developed countries to developing countries are exceptions such as Norway that has a very successful and increasing salmon farming industry (FAO 2012c). Unlike the US, which has devoted more energy to regulations and trade barriers to reduce competition (Knapp *et al.* 2007), Norway's success in salmon farming is based on technological support, knowledge of the sea and fishing, economic incentives, modern management, and marketing strategy (Chu *et al.* 2010). Aquaculture in Norway is expected to continue to grow due to the favourable consequences of climate change and a reduced dependence on fishmeal imports (Merino *et al.* 2012). On the other hand, some developing countries have failed to develop aquaculture industries, such as some countries in Africa and Latin America, the reasons for such failure mainly are the lack of well-developed markets or the ability to reach them, weak institutional systems and lack of investment (Bostock *et al.* 2010).

World freshwater aquaculture production in 2005 averaged 0.17 mt ha^{-1}, which indicating potential for a 20-fold increase in world aquaculture production (Gjedrem *et al.* 2012). Intensification can generate more yields in much of the existing extensive and semi-intensive farming systems and the means to promote intensification is increasingly available (Muir 2005). Marine culture also has potential for quick growth, if the world average production per km coastline increases from the present level of 103 mt km^{-1} to 240 mt km^{-1} coastline, which has been exceeded by three countries (China, Republic of Korea and Thailand) (Gjedrem *et al.* 2012). Hence, there is a substantial potential for further productivity growth, and for aquaculture products to become less costly (Asche *et al.* 2008).

4. Chapter 4 A comparative analysis of four internationally traded farmed seafood development in China

4.1. Introduction

Aquaculture has the fastest growth rate among all agriculture and food sectors (FAO 2012c), and is now contributing nearly 50% of global seafood consumption (De Silva 2012). Seafood is also the most important global traded agriculture product (FAO 2012c). High value species such as crustaceans and low value species such as tilapias and catfishes are the most important global traded farmed seafood commodities (FAO 2009b). Crustacean production accelerated after 2000 with an average annual growth rate of almost 15% in the period 2000-2008, much faster than the growth of finfish and molluscs (Bondad-Reantaso *et al.* 2012). Among all the farmed crustaceans, whiteleg shrimp (*L. vannamei*) expanded quickly since 2000, now ranking number one for production value, and in the top 10 by production quantity for global aquaculture species (Stentiford *et al.* 2012). Shrimp are now the most important internationally traded fishery commodity in terms of value and the most valuable fishery export for many tropical developing countries (FAO 2009b; Bondad-Reantaso *et al.* 2012), and aquaculture has been the main force behind the increased shrimp trade during the past decade (Asche & Khatun 2006). Another significant part of global crustacean farming is freshwater prawns such as *Macrobrachium spp.* expanding quickly, especially in China (Stentiford *et al.* 2012). Global production of freshwater prawns expanded from less than 3,000 mt in 1980 to almost 444,000 mt with an annual farm-gate value USD 2.2 billion in 2009 (New & Nair 2012). Wild-caught and farmed macrobrachium are already being exported by Bangladesh and India (New 2010). Strongly hierarchical and cannibalistic behaviours have made more intensive production, such as is possible for shrimp, problematic (New 2010; Brown et al. 2010). Culture systems tend to be diverse and use a moderate level of inputs which may be an advantage in terms of sustainability (New 2010; Kutty & Miao 2010). In addition to high valued species like shrimps, a number of high-volume but relatively low-value species including tilapias and catfish are also traded in large quantities at the international level (FAO 2009b). The export growth rates for catfish and tilapias exceeded 50% per year in some years (FAO 2009b). Tilapias have become international fish instead of African fish, gaining more market and consumer acceptance (Hussain 2004). Tilapia production may well surpass that of carps due to a much wider distribution of production and consumption and a huge base of value-added product forms (Fitzsimmons 2011b). The recently emerged important seafood in global market, Vietnam's striped catfish (*P. hypophthalmus*) was seen as a great success by many people, and its development was more connected to international market than many other types of farmed seafood (Belton *et al.* 2011; De Silva & Phuong 2011; Nguyen & Dang 2010; Phan *et al.* 2009). Four categories of farmed seafood, tilapia, penaeid shrimp, macrobrachium prawns and striped catfish, have emerged as important farmed seafood commodities in the world, for which their production is concentrated in Asia (SEAT 2010).

China plays the most important role in the global aquaculture and seafood trade and is the biggest producer of shrimp, tilapia, and macrobrachium prawns (FAO 2012c). Chinese seafood exports are mainly of farmed species, of which a few categories dominate namely shrimps, shellfish, tilapias, eel, large yellow croaker, red swamp crayfish and channel catfish, these categories accounted for 50% of total export value in 2011 (Yu, 2012). Traditional carps farmed in freshwater still dominate Chinese aquaculture production overall, accounting for 41.5% of total aquaculture production in 2010 (MOA 2012). Now carps remain popular in domestic markets, but they have limited demand in international markets, the rise of China as an exporter has been linked to shrimp from coastal ponds, and more recently tilapias from inland systems. In common with other countries that developed coastal shrimp farming in the 1980-90s, China's shrimp industry has been marked by international criticism of the environmental impacts, cyclical productivity linked to disease epidemics, reliance on wild fish stocks as the basis of shrimp feed and trade interruptions related to public health concerns in importing countries (Naylor *et al.* 2009; Xie *et al.* 2004). Tilapias have had a less chequered advance, being essentially herbivorous and although suitable for culture in a variety of systems, largely substituting for carps in inland ponds (Lai & Yang 2004). In contrast to carps, tilapias, known as 'aquatic chicken' (Maclean 1984), have proved to be an effective substitute white fish on international markets and China quickly moved to dominate the rapidly growing international trade, firstly through whole fish and more recently added value products (Fitzsimmons 2006). While exports have grown rapidly, however, local purchasing power has driven domestic demand for shrimp, tilapia and the wide range of other farmed products including freshwater prawns for which export markets remain undeveloped in China. Although freshwater prawns have a growing international niche market as demonstrated by established exports from other countries in Asia such as Bangladesh to Europe (Ahmed *et al.* 2008), the expansion of macrobrachium farming in China was seen as a surprise by New (2010). The output from Chinese farming is consumed entirely domestically. The importation of numerous other exotic species with export potential such as striped catfish, mainly cultured for the global trade in the Mekong delta, was also introduced into China on an experimental basis (Lou 2000), but still remained unfulfilled (Liu, 2011).

Tilapia, penaeid shrimp, macrobrachium prawns and striped catfish therefore represent four widely different products in terms of life history, tolerance levels, resource demands and export potential. A comparison among the four commodities is likely to prove more insightful than an investigation of any one.

This section examines the development of four internationally-traded farmed seafood commodities, tilapias, penaeid shrimps, macrobrachium prawns and striped catfish in China, to find out how have these species become differentiated in terms of production and access to domestic and international markets. The main research questions are:

1. What factors explain the differential rates of expansion of these four categories of farmed seafood?

2. What factors have driven the orientation towards export or domestic markets?

3. What factors affect the sustainability of the export trade and how do these affect the future outlook for the trade?

4. What role do organisations and intermediaries play in the development process of these farmed seafood value chains?

4.2. Expansion – historical perspective and species diversification for domestic and export market niches

Production of both tilapia and the penaied shrimp now exceed one mmt each and as such, make China the global leader for both commodities. Both tilapia and penaied shrimp that now dominate production are based on multiple introductions and transfers over recent years. In contrast freshwater prawns appear to have stabilised at less than half this level (<400,000 mt). The last two decades have been characterised by very different patterns of growth among the three types with shrimps showing a rollercoaster pattern of surges followed by decline and then yet faster growth, tilapias having a slower start followed by continuous and rapid growth and freshwater prawn demonstrating steady growth before levelling off (Figure 4.1).

The initial analysis revealed that of the four farmed seafood commodities considered, striped catfish had not developed beyond a research candidate since its introduction from Vietnam in the 1970s (Lou 2000). The fisheries department and local fisheries companies had trialled it, but it had failed to show promise (Liu, 2011). In contrast, the ictalurid, channel catfish (*Ictalurus punctatus*) since its introduction from the US in 1984 (Lou 2000) has expanded to meet both domestic and international markets, having an average annual growth rate of 35% from 2003 to 2009 and reached a production level of 223,233 mt in 2009 (FAO 2010b). In addition, indigenous catfish such as the Amur catfish (*Silurus asotus*) remain dominant in catfish farming with an annual production 325,268 mt in 2009 (FAO 2010b). Whereas the channel catfish is within its normal climatic range and amur catfish is an indigenous species, striped catfish is well outside its native range and thermal tolerance (12℃, lower lethal temperature; (Fu 2002)). However, winter temperatures regularly fall below this range even in the southern most provinces Guangdong and Hainan province (Guangdong Meteorologic Service 2014; Hainan Meteorologic Service 2014). Striped catfish and channel catfish are substitutes in the major export market – the US – but that the required culture conditions are very different. Another limitation for striped catfish has been a low competitive advantage compared with the Vietnamese striped catfish industry caused by higher cost, lower production, inferior breeding and processing techniques and yellow flesh colour (Liu, 2011).

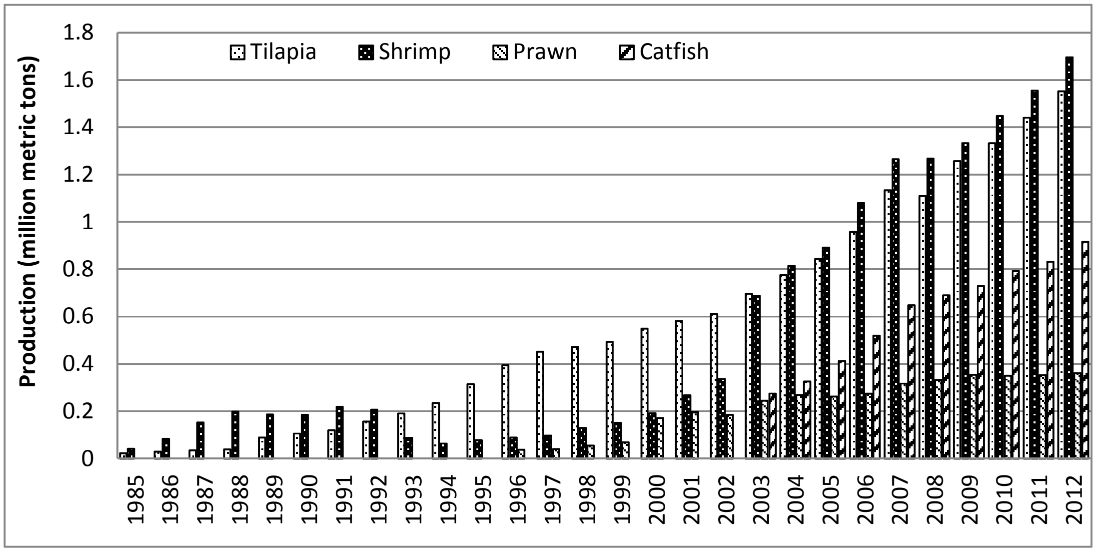


Figure 4.1 China annual production of tilapia, shrimp, prawn and catfish production in 1985-2012

(Source: FAO 2014)

As with the striped catfish, tilapias were also first introduced from Vietnam to the south of China in the 1950s as the hardy but slow growing *Oreochromis mossambicus* (Lai & Yang 2004). Current strains are mainly Genetically Improved Farmed Tilapia (GIFT) strains of Nile tilapia (*O. niloticus*), the hybrids of blue tilapia♂×Nile tilapia♀ (*O. aureus*×*O. niloticus*♀) also call *Ao-ni* in China, and Red tilapia (*O. mossambicus*♀×*O. niloticus*♂) (Hanson *et al.* 2010). Despite less than optimal conditions, China now produces in excess of 45% of world tilapia production, having grown at an average annual rate of 20% between 1979 to 2010 compared to a global average of 12% annum^{-1} (FAO 2010b). Prolonged cold winters, such as 2008, cause large-scale mortalities and set back the industry (Hanson *et al.* 2010). The highest annual production growth rate occurred in the years between 1985 to 1995, after the introduction of new strains, success in all-male tilapia seed producing and improvement in both nursing and grow-out technologies (Zhang *et al.* 2011). Available of good strains, availability of labour skilled in basic husbandry, large amount of water area, new markets, together with the broad-based aquaculture experience promoted tilapia expansion quickly (Zhao 2011). The environmentally friendly nature of farming tilapia growing international trade, diversified production strategies and strong domestic markets are expected to continue driving tilapia farming growth (Fitzsimmons 2008). State support has been relatively limited; aiming to raise rural farmers' income, subsidies that ranged between USD 300-500 ha^{-1} were provided to farmers to build new tilapia ponds by local government to stimulate tilapia farming (Bean & Wu 2006). Although total production continues to increase, growth rates have fallen in recent years, related to a reduction in margins as both input costs have increased and the Chinese Yuan (CNY) has appreciated (Hanson *et al.* 2010), together with the effects of unstable climatic conditions and disease outbreaks (Thodesen *et al.* 2011). Limitations in the growing season and water availability are also believed to reduce rates of growth (Liu 2010; Li & Qiu 2010). According to Hanson *et al.* (2010), tilapia production in China will remain stable, for the economic returns of the industry are too low and cannot provide enough incentive for further expansion of tilapia farming and processing.

The pattern in penaeid shrimp production over recent years has been related to major shifts in the key species cultured following major disease impacts in the early to mid- 1990s (Briggs *et al.* 2005; Lee 2010; Clarke 2009). Before that, shrimp farming in China expanded 200-fold from 1978 to 1988 (Clarke 2009) based on the technical breakthrough of large-scale artificial propagation and cultivation of fleshy prawn (Li 2007; Zhou 2010), partly based on the success of artificial formulated feed research (Zhao 2007), and partly related to market incentives (Hall 2004). A growing demand for shrimp, mainly from importing markets, coupled with a levelling-off of the production from capture fisheries, gave rise to high market prices in the 1980s (Neiland *et al.* 2001). However, following major disease breakouts, as well as poor performance, slow growth rate of the major indigenous cultured shrimp species, stimulated a shift in the main farming species (Briggs *et al.* 2005) away from the fleshy prawn (*Fenneropenaeus chinensis*) to the exotic whiteleg shrimp *(Litopenaeus vannamei).* Black tiger shrimp (*Penaeus monodon*), kuruma prawn (*Marsupenaeus japonicus*) and limited quantities of *F. chinensis* make up the balance. Introduction of *L. vannamei* accelerated growth of the industry in the years after 2000, especially the introduction of specific pathogen free (SPF) shrimp stock from Hawaii (Lee 2010; Wang *et al.* 2005), and hatchery techniques for the shrimp being established. Commercial culture of the species began in the late 1990s utilising the thousands of empty shrimp ponds left by collapsed shrimp farming in 1990s (Liu & Li 2010; Wang *et al.* 2005), development of intensive shrimp farming system in intensive pumped systems in coastal areas (Lai 2009) and freshwater inland sites. *L. vannamei* farming had been successfully demonstrated in freshwater, based on the wide range of salinity tolerance of this species (Zhang 2000). Since then the average annual growth rate of shrimp production has exceeded 25%. Production data of *L. vannamei* farmed in freshwater was first collected by FAO in 2003, indicating that it constituted approximately half of production, since *L. vannamei* production seemingly doubled in a single year from 2002 when production data was only based on brackishwater. Stocking *L. vannamei* derived from imported pathogen-free broodstock into more bio-secure systems resulted in major gains in consistency and expansion of production area away from limited conventional coastal locations (Lai 2009). Biological characteristics of *L. vannamei* made the species suitable for high stocking density, good tolerance of a wide range of salinities and temperatures, lower protein feed requirement, lower FCRs, higher disease resistance and survival rates, ease of breeding and domestication, and higher meat yield all contributed to its success (Briggs *et al.* 2005). However, the rapidly increasing production of *L.*

vannamei has led to serious and continuing price depression in global markets (FAO 2006) and the industry has continued to be impacted by problems such as diseases. In the survey conducted by Liu *et al.* (2010) in the main shrimp producing areas, 71% of shrimp farmers thought shrimp farming was at risk because of diseases, investment requirements and low market price, and only 25% remained optimistic about the prospects for shrimp farming.

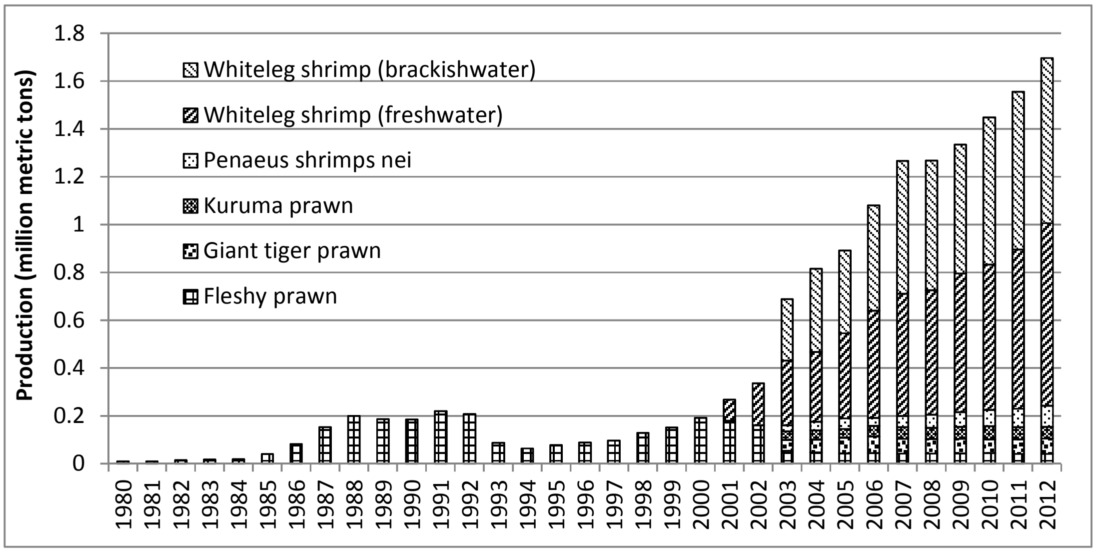


Figure 4.2 Annual production of whiteleg shrimp (*L. vannamei*) in brackishwater and freshwater, giant tiger prawn (*P. monodon*), fleshy prawn (*F. chinensis*) and kuruma prawn (*M. japonicus*) in China in 1980 to 2012 (Source: FAO 2014)

China is also the largest global producer of macrobrachium prawns (FAO 2010b). The total value of the freshwater prawn farming sector was more valuable than tilapia farming in China (New & Nair 2012). Prawn culture started with oriental river prawn (*Macrobrachium nipponense*) at the end of 1950s, but grew very slowly until 1990 (Feng *et al.* 2008). The first motivation for prawn farming, mainly was seen as a substitute in the market for farmed marine shrimp during the period of severe contraction in Chinese farmed marine shrimp production that occurred in the early 1990s (Feng *et al.* 2008; New & Kutty 2010). Mainly two species of macrobrachium are now farmed in China; the oriental river prawn (*M. nipponense*) is only cultured in China, and China now accounts for more than 60% of world production of giant river prawn (*M. rosenbergii*) in 2009 (FAO 2010b). The *M. nipponense* is a native species and a traditional inland capture fishery product (New 2005; Feng *et al.* 2008) and *M. rosenbergii* is exotic was multi introduced into China since 1970s (New 2010). The productions of *M. nipponense* and *M. rosenbergii* have both increased since 1996 with an average annual growth rate of 12.5% and 8.5% respectively. *M. rosenbergii* farming expanded quickly in the 1990s mainly due to technological advances in large-scale artificial hatching and nursery rearing, in response to challenges from out-breaks of penaeid shrimps diseases, and innovative live-transport technologies (Yang *et al.* 2012). The production of *M. rosenbergii* fell around the year 2003 due to renewed competition with shrimp as the widespread farming of *L. vannamei* expanded (New & Kutty 2010; Yang *et al.* 2011), an outbreak of white-body disease during 2002-2003 (Yang *et al.* 2011), and decreased product value. Additionally there were marketing problems (consumers preferred *M. nipponense*), transport and processing problems as live prawns were in greatest demand (New & Kutty 2010). Its low edible proportion and sensitivity to temperature change were also disadvantages (Huang et al. 2007). Juvenile production of *M. rosenbergii* had problems in 2010, causing another decline in production (Pan & Xu 2010). In spite of these setbacks the *M. rosenbergii* farming industry in China is a nearly one billion USD business now, including seed, feed, processing, domestic and international sales (Yang *et al.* 2012). The total farming area of *M. rosenbergii* was about 30,000 ha, with a total production of 150,000 mt in 2010 (Fu *et al.* 2012).

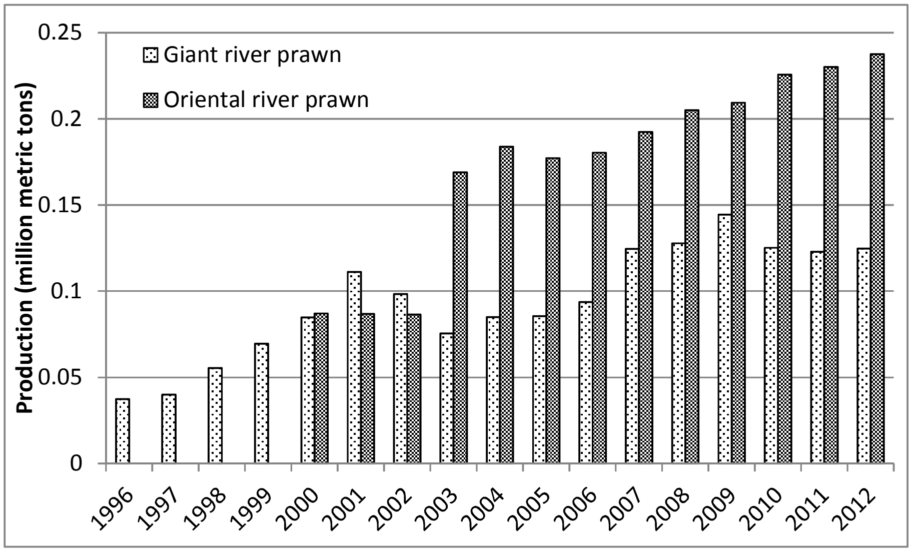


Figure 4.3 Annual production of giant river prawn (*M. rosenbergii*) and oriental river prawn (*M. nipponense*) in China

(Source: FAO 2014)

M. nipponense is an indigenous species naturally distributed throughout China, including the rivers, lakes, reservoirs and ditches from the south to the north (Fu *et al.* 2012). The farming of *M. nipponense* began in the 1950s and expanded rapidly in 1990s, after reaching a peak in 1999 or 2000 and thereafter maintained a stable production for 10 years up to the present with a farming area of about 400,000 ha year^{-1} and a farmed production of around 200,000 mt year^{-1} including monoculture and polyculture (Fu *et al.* 2012). The characteristics of *M. nipponense* such as tolerance to cool temperatures, marketability yea-round, easy availability of seed by self-recruitment and the relatively simple rearing and breeding techniques required have proved positive. In addition, it's relatively short culture cycle, and popularity with local consumers on account of its good taste and tender texture, make it more popular than *M. rosenbergii* for culture in spite of its smaller marketable size (Kutty & Miao 2010). Increasing domestic market demand and high economic returns were seen as the main reasons of rapid growth in Macrobrachium production (Kutty & Miao 2010). *M. nipponense* had far less price competition pressure than *M.*

rosenbergii, partly as it benefits from a long harvesting season and thus avoids over supply that affects *M. rosenbergii* during its short harvest and marketing period. The lack of market pressure is a major reason for the maintenance of higher unit values for *M. nipponense* (Kutty & Miao 2010). Also the pressure on producer margins caused by the higher level of intensification and yield make the species vulnerable to declines in farm-gate prices (Belton & Little 2008), the low intensification of *M. nipponense* farming and lower yield level than *M. rosenbergii* also make it lack of market pressure and maintains high price.

In inland areas, culture of *L. vannamei* in freshwater was also more competitive than macrobrachium. Increasing production of *L. vannamei* in freshwater reflected not only to its market acceptability, but also higher yield and a longer culture period than *M. rosenbergii* in the more temperate climatic conditions prevalent in many Chinese growing areas (New & Kutty 2010).

Compared to more stable growth pattern of macrobrachium, another alien species, red swamp crawfish (*Procambarus clarkii*), also viewed as a kind of freshwater prawn in China, expanded rapidly in recent years. The total production increased more than 12-fold in ten years from 44,570 mt in 2003 to 554,281 mt in 2012 (MOA 2013). The driver of red swamp crawfish culture take off was huge domestic market demand stimulated by innovation in the cooking methods and establishment of export markets (Liu & Li 2010). More than half of red swamp crawfish is produced in inland Hubei province, where lack competition from penaeid shrimp or macrobrachium prawns, and red swamp crawfish can farm in paddy field, which makes it popular in most of rice producing areas (Shen *et al.* 2012). Due to high price in domestic market and low edible meat yield (around 18%) after processing, most of production was consumed domestically (Yang & Zhu 2013). Total export volume was 28,288 mt in 2013, with US alone imported 16,324 mt, followed by EU 8,205 mt and ASEAN countries 3,039 mt (China Customs 2014).

China has become the leading global exporter of tilapia and shrimp products in recent years. In 2007, China mainland accounted for more than 77% of global tilapia exports by volume (FAO 2010c) and the second largest exporter by volume and third largest exporter by value of shrimp/prawn products in the world. The growth rate of tilapia and shrimp export volume between 2002 and 2010 averaged 36% and 12% respectively (FAO 2010c). Tilapia production capacity gradually shifted from Taiwan province of China to mainland China (Josupeit 2005), with exports from mainland China surpassing Taiwan in 2002 (Hanson *et al.* 2010). The move reflected the transfer of know-how and capital from Taiwan (Josupeit 2005) but also the lower labour costs and richer farming resources (Hanson *et al.* 2010; Lindkvist *et al.* 2008; Belton *et al.* 2009; Josupeit 2005) on the mainland together with a favourable national regulation regime (Lindkvist *et al.* 2008), larger production areas and production potential (Josupeit 2005; Belton *et al.* 2009) and a favourable currency exchange rate (Li & Huang 2005).

Shrimp is a long established export commodity of China, and remains the most important exported seafood by value, and considered as an important way to enhance farmers' income and create jobs (Ning & Liao 2008). Exported volumes showed similar trends to farmed shrimp production, peaking in 1990, before declining in the face of large-scale shrimp disease outbreaks. A recovery occurred after 2000 at the same pace based on soaring farmed *L. vannamei* production. However, shrimp exports actually declined after 2008 because of trade barriers (Yang & Yang 2008), recession in importing countries (Lei, 2009), the gradual appreciation of the CNY (Chen & Ning, 2008), increased labour costs and increased domestic demand (Lin 2010).

Compared with the large volumes of shrimp and tilapia exports, the potential for *M. nipponense* and *M.rosenbegii* export are still underdeveloped (Kutty & Miao 2010; New 2005), mainly due to the small harvest size and undeveloped post-harvest technologies for *M. nipponense* (Kutty & Miao 2010) and the high domestic price of *M. rosenbergii* (New & Kutty 2010). Chinese consumers particularly value freshwater prawns and are willing to pay a much higher price than traditional cultured fish species (Kutty & Miao 2010; New & Nair 2012) and the prevailing international price for prawns making export unattractive.

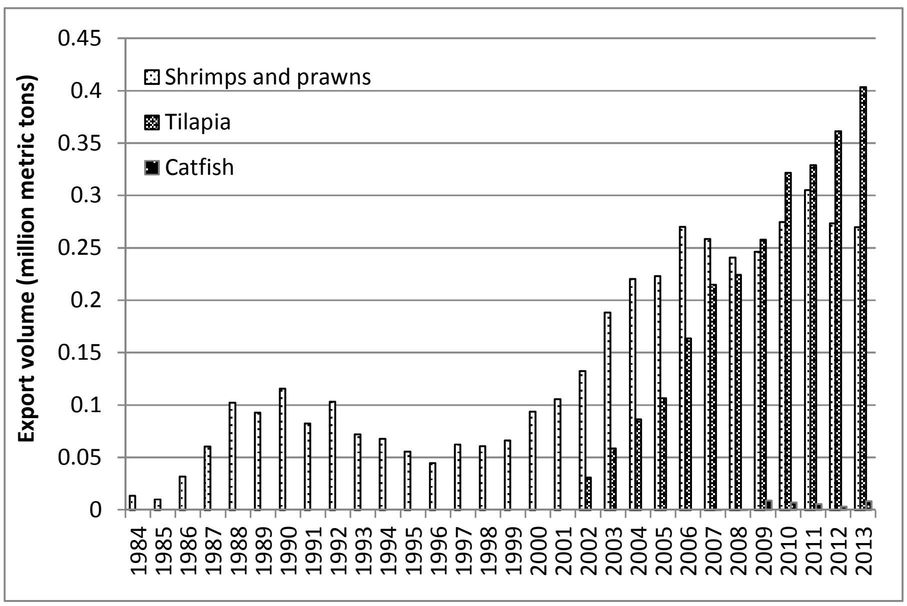


Figure 4.4 Quantity of China's tilapias, shrimp and catfish export in 1984-2013

(Source: FAO 2014; China Customs 2014)

There is also a clear trend towards greater value-added for both exports of tilapia and shrimp although there are some anomalies for tilapia for which prepared meals appear to have declined in favour of fillets after making up the majority of exports in 2007 and 2008. This change may be related to greater price sensitivity of consumers in export markets affected by the global recession resulting in lower price fillets becoming more popular. But in the future, further product diversification is likely and that China will try to shift from frozen whole tilapia, frozen fillet tilapia to higher value-added products through establishing their own brands (Hanson *et al.* 2010). Although imported seafood products such as tilapia are repackaged by importing wholesalers in Europe at present, it is anticipated over the long-term that packaging for the retail segment will move towards supplier countries (CBI 2013a), which means more value-added products such as prepared and preserved products[6] will be produced in supplier countries. However, as lead firms who need frequent changes in food presentation and style reacting to food fashion, some secondary processing such as sauces, coatings can be added cost effectively in import countries.

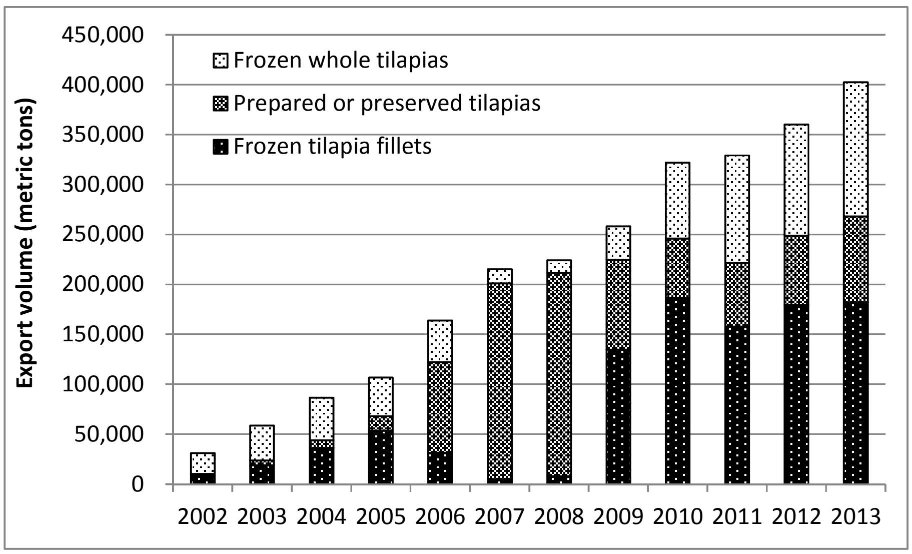


Figure 4.5 Composition of export tilapia product in 2002-2013

(Source: FAO 2014; China Customs 2014)

The production and export of tilapia from China is all based on farmed sources, because tilapias are exotic and there is no large-scale exploitation of wild stocks (MOA 2013). But for shrimps and prawns the story is much more complex: not only do both wild and farmed shrimp contribute, but also for the names of the species are not consistent. The English terms for different species of

[6] The term comes from the Harmonized Commodity Description and Coding System, although no clear definition is provided. It usually refers to value added products in retail packaging and ready to sell.

shrimps and prawns are not clear and often confused, such as *P. monodon, F. chinensis and M. japonicus* being categorised as prawn and *L. vannamei* as shrimp in FAO aquaculture production and trade database (FAO 2010b). In different areas the definition for shrimp and prawn is not same, such as in the UK both shrimp and prawn means penaeid shrimp and prawn means freshwater macrobrachium, but in the US shrimp mean all species of shrimp and prawn, while in Australia prawn is used interchangeably for penaeid shrimps (Ministry of Commerce 2005).

In China, all shrimp and prawns, even red swamp crawfish have the same common Chinese name – *xia*, and professional knowledge is required to differentiate them. Fortunately, as export data for red swamp crawfish were collected separately (FAO 2010c), farmed freshwater prawns were reported as not exported in significant volume (Kutty & Miao 2010; New 2005), the major part of shrimp exports were penaeid shrimps from farmed and wild sources.

China still has a big shrimp fishing industry. Despite a gradual decline since 2000, the production of marine shrimp fishery was 1,475,426 mt, including 107,618 mt of penaeid shrimps in 2009, while the production of freshwater prawn fishery was 275,318 mt in the same year. The total shrimp and prawn fishery production was similar to farmed production if red swamp crawfish were excluded (MOA 2010b). Some areas are famous for shrimp fishing and export such as Zhoushan district in Zhejiang province (Clarke 2009), but its export volume is mixed with the total shrimp and prawn export data in the FAO database, and some shrimp 'exports' are possibly re-exports. A cross check between data from China Custom and FAO FishStatJ database, reveals some differences between product categories, some categories being specified as species mainly from the fishery (Zhejiang Zhoushan Port-of-Entry 2004), and some categories still unclear in terms of species and origin (farmed or wild sources) (Table 4.1).

Table 4.1 Comparison of shrimp and prawn products categories between FAO FishStatJ database and China Custom data

Products categories in FAO FishStatJ database	Products categories in China Custom	The main species (Zhejiang Zhoushan Port-of-Entry 2004)	Farmed or wild
Shrimps and prawns, peeled, frozen	Penaeid shrimps, peeled, frozen	*L. vannamei, F. chinensis, M. japonicus*	Farmed
	Small shrimps, peeled, frozen	*Solenocera melantho, Parapenaeopsis hardwickii*	Wild
Shrimps and prawns, frozen, nei	Penaeid shrimps, shell on, frozen	*L. vannamei, F. chinensis, M. japonicus*	Farmed
	Rest of small shrimps, shell on, frozen	*S. melantho, P. hardwickii*	Wild
Shrimps and prawns, not frozen, nei	Rest of small shrimps and penaeid shrimps, not frozen, seed excepted	Not specified	Uncertain
Shrimps and prawns, fresh or chilled, nei	Penaeid shrimps, fresh or chilled, seed excepted	Penaeid shrimps	Farmed
Shrimps, prawns, prepared or preserved, nei	Shrimps, prawns, prepared or preserved	Not specified	Uncertain

Note: nei, not elsewhere included

Table 4.1 shows the type of problem in understanding the complexity of the system, but as the export volume has same trends in farmed *L. vannamei* production, and production for other shrimp species remains stable, it can be deduced that the increasing shrimp exports have been driven by increased production of farmed *L. vannamei* (Chen & Ning 2008), other penaieds except *L. vannamei* also have a higher price and mainly consumed domestically. In the China Entry-Exit Inspection and Quarantine Bureau (CIQ) export-oriented registered farms list, 90% shrimp farms were specified for *L. vannamei*, the remaining 10% of shrimp farms do not specify particular species, among these shrimp farms for *L. vannamei*, around 9% also farm *P. monodon* (AQSIQ 2010). The major reasons for the dominance of *L. vannamei* exports, include the comparatively fast growth, high resilience and high production of farmed *L. vannamei* (Chen & Ning 2008), higher meat yield (at 66%–68% compared to *P. monodon* at 62%) and being preferred by markets such as US (Briggs *et al.* 2005). In the following context, shrimp export products may be classified as wild shrimp for these categories specified for wild shrimp, and farmed shrimp including categories specified as farmed shrimp and uncertain categories.

The export volume of wild shrimp products is around 50,000 mt annually, but the proportion of wild shrimp in export volume dropped from more than 60% in 2000 to around 20% in recent years, while the export volume of farmed shrimp products declined in recent years after peaking in 2006.

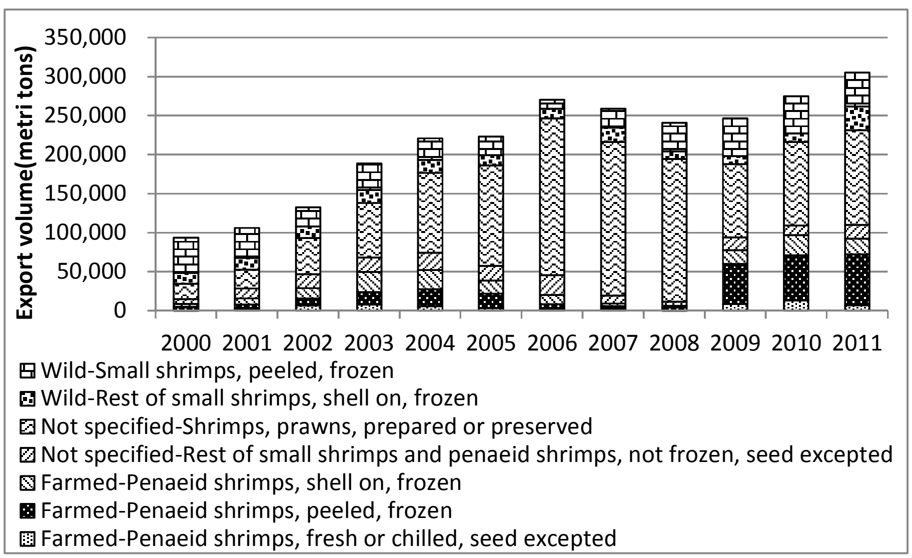


Figure 4.6 Shrimp and prawns export quantity in China in 2000-2011

(Source: China Customs 2014)

4.3. Concentration of production and export

There are important geographical characteristics of production for tilapias, shrimp and prawns, particularly with regard to export. The main production areas of tilapia and shrimp are the Eastern coastal provinces, particularly those in South east China, including Guangdong, Guangxi, Hainan and Fujian, while the main producing area of macrobrachium prawns is Jiangsu Province situated in the central eastern part of China. The Northeast, Middle and West produce relatively little (Figure 4.7).

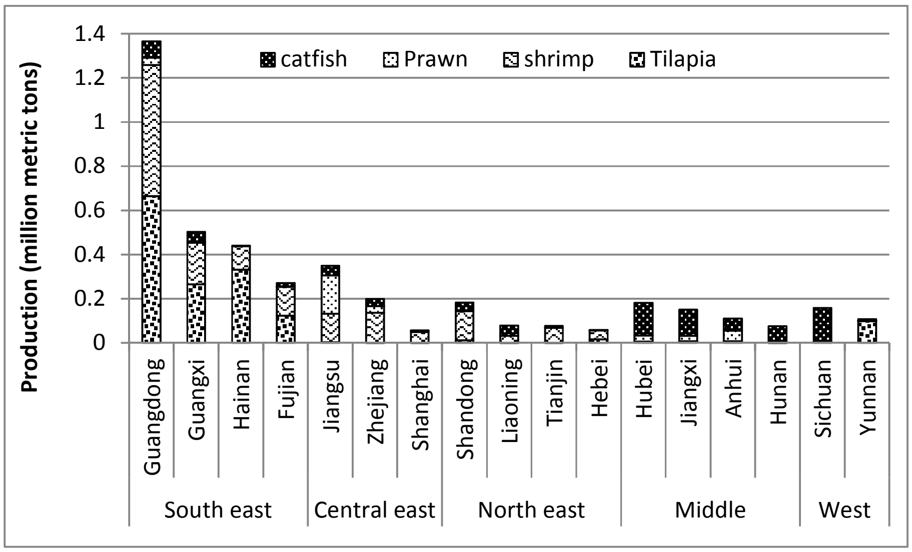


Figure 4.7 Distribution of tilapias, penaeid shrimp, macrobrachium prawns and catfish production in China in 2012

(Source: MOA 2013)

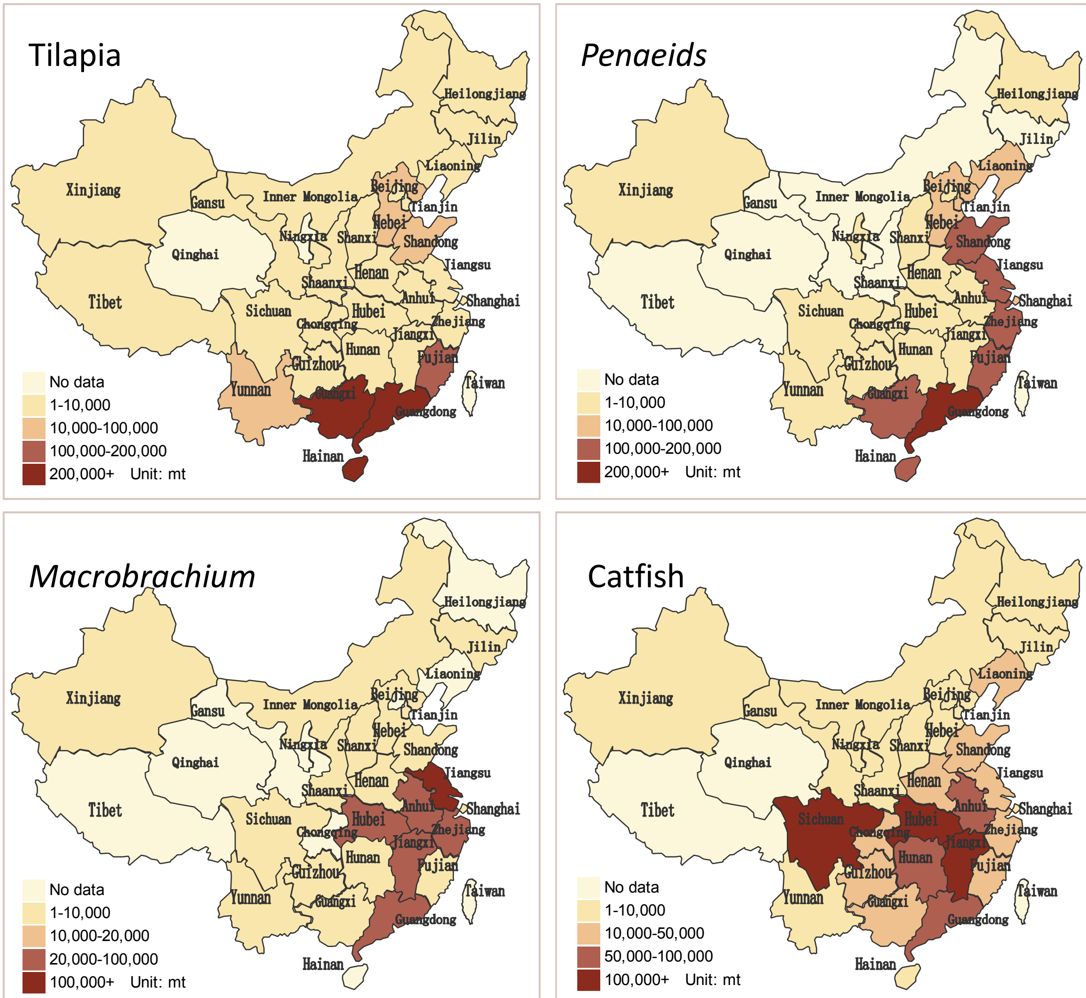


Figure 4.8 Data map of tilapia, penaeid shrimp, macrobrachium prawn and catfish production by province in China in 2012

(Source: MOA 2013)

All the main tilapia-producing provinces in China are located in tropical or sub-tropical regions[7], where tilapia are cultured and supplied year round due to the warm climate and high rainfall. The sectors is well established, has a large total farming area, good hatcheries and a complete tilapia value chain, as well as the favourable policy and huge market demands (Liang & Liang 2009; Pan 2007). The top three producing provinces Guangdong, Hainan and Guangxi produced more than 80% of total production (MOA 2012). Tilapia produced in northern areas can be farmed over a

[7] http://en.wikipedia.org/wiki/File:World_map_indicating_tropics_and_subtropics.png

shorter grow-out period, and/or requires over-wintering measures such as protected cover (polytunnel) warm ground water or hot water from power plants (Lian 2005). The shorter growing-out period and requirement for over-wintering increases production costs and has limited tilapia expansion in these areas.

As with the production, the main export area of tilapia and shrimp are concentrated in the southeast and central eastern part of China (Figure 4.9). However, export is concentrated to a few provinces in the Southeast China.

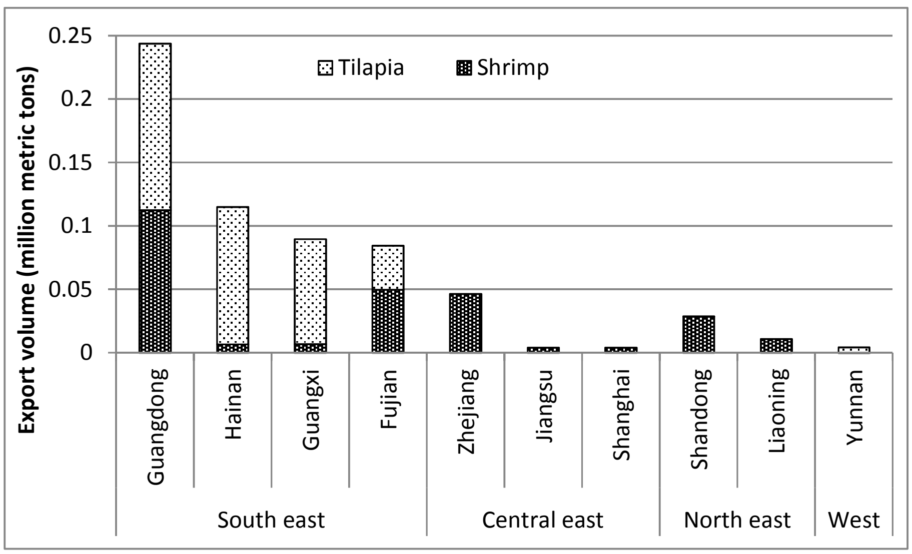


Figure 4.9 Distribution of tilapias and shrimp exports in China in 2012

(Source: China Customs 2014)

Tilapia production only began to grow dramatically at the beginning of the Millennium in the main exporting provinces such as Guangdong, Hainan and Guangxi, in contrast to the production from other provinces remains stable (Figure 4.10), suggesting the growth was largely driven by the export market.

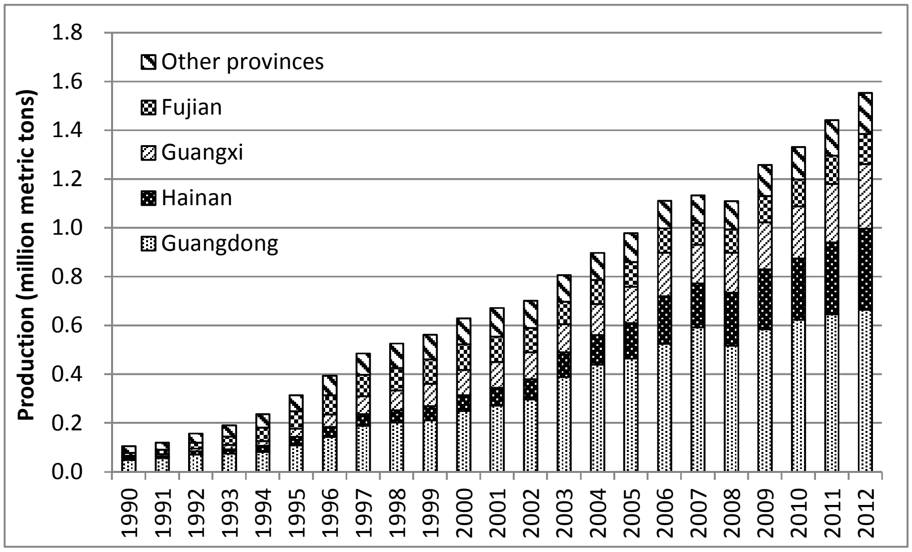


Figure 4.10 Tilapia production in the main producing provinces

(Source: MOA 2013)

The main production areas for farmed shrimp shifted geographically after 1992 when diseases started to reduce the production of the *F. chinensis* produced mainly in its natural range in North East China, including Shandong, Liaoning and Hebei. After 2000, the introduction of *L. vannamei* into China, has caused a shift in shrimp farming from north to south and from being confined to the coastal zone has expanded also to inland freshwater sites. The major provinces, Guangdong, Guangxi, Jiangsu, Zhejiang, Shandong and Hainan are located along the Chinese coastline, where all the hatcheries are concentrated and sufficient high quality marine or brackish water is available. Even shrimp as *L. vannamei* farmed in freshwater still needs brackishwater in the juvenile stage (Figure 4.11). There are clear differences in distribution of species with *F. chinensis* and *M. japonicus* being largely confined to the north and *P. monodon* and *L. vannamei* to the south, although the latter is also raised in freshwater sites in more northerly-located provinces e.g. Jiangsu and Zhejiang.

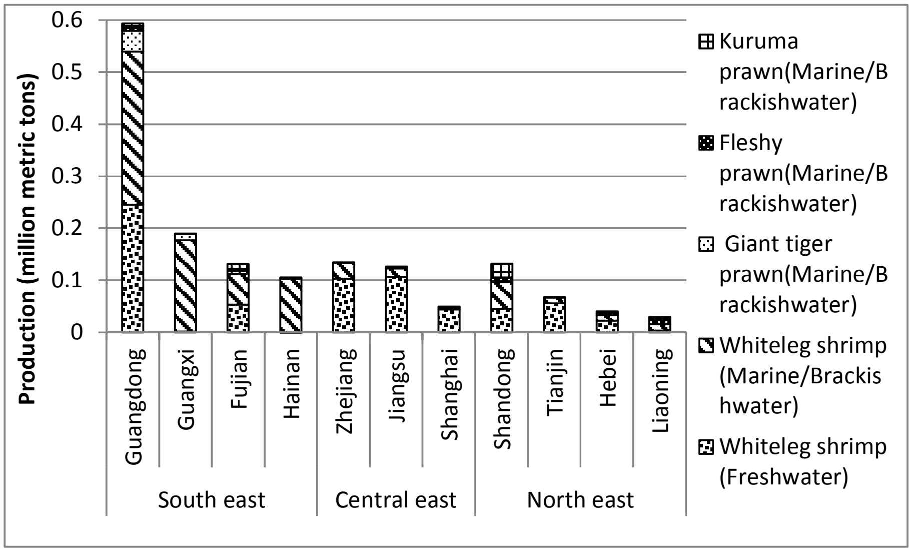


Figure 4.11 Distribution of different shrimp species production in different water type in China in 2012

(Source: MOA 2013)

Compared with tilapia, shrimp production was less geographically concentrated, and the production increased in most producing areas, driven by domestic market demands (Figure 4.12).

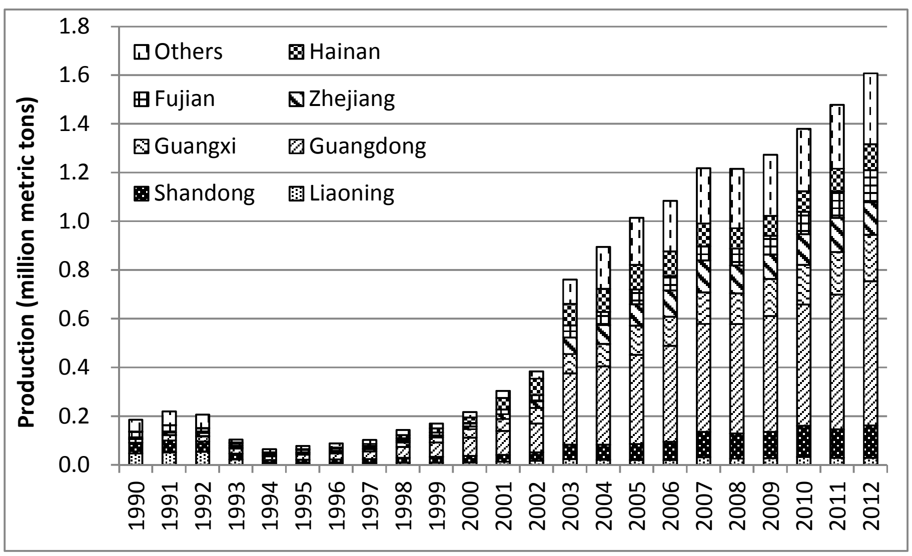


Figure 4.12 Shrimp production in the main producing provinces

(Source: MOA 2013)

Most macrobrachium were produced in the central eastern part of China, especially Jiangsu Province, which account for more than half. Macrobrachium was raised less intensively than shrimp and required relatively more freshwater resources, which are abundant in the lower reaches of the Yangtse River within Jiangsu Province. The main *M. nipponense* producing provinces are Jiangsu, Anhui and Zhejiang, where *M. nipponense* is naturally distributed, and the main *M. rosenbergii* producing provinces are Jiangsu and Guangdong. Chinese consumers prefer live prawns but the cost and difficulty of live transportation of has led to the market for *M. nipponense* being mainly concentrated in central east China (Kutty & Miao 2010).

The export product forms also shows a concentration in particular areas for tilapia. The most value added product – prepared or preserved tilapia – are mainly exported from Guangdong province, especially from Zhanjiang district (38.7%) and Maoming district (16.5%). For shrimp the most important area for prepared or preserved shrimp products export is Guangdong province too, especially in Zhanjiang district (32.4%) and Yangjiang District (19.3%). Around half (49.5%) of wild shrimp (other small shrimps, shell on, frozen and small shrimps, peeled, frozen) for export came from Zhoushan district in Zhejiang province, which is one of China's largest fishing ports (Clarke 2009).

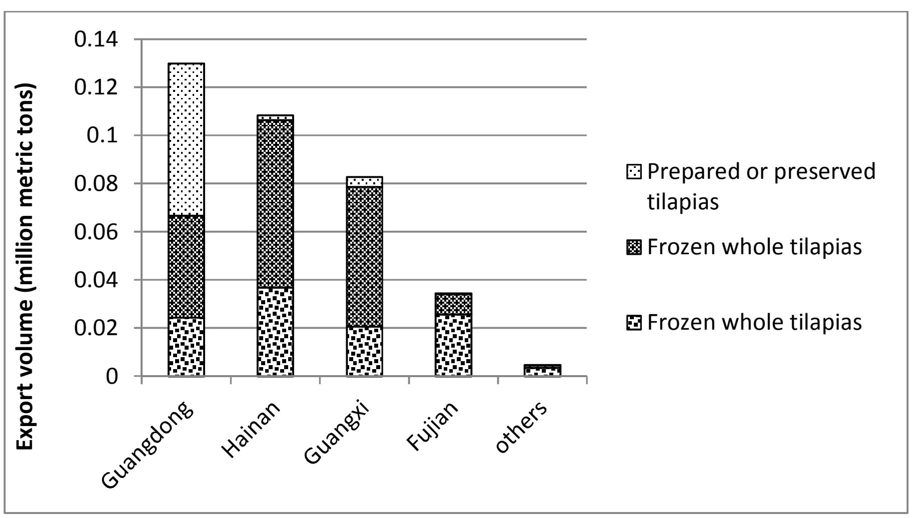


Figure 4.13 Distribution of production of different tilapia products for export in China in 2012

(Source: China Customs 2014)

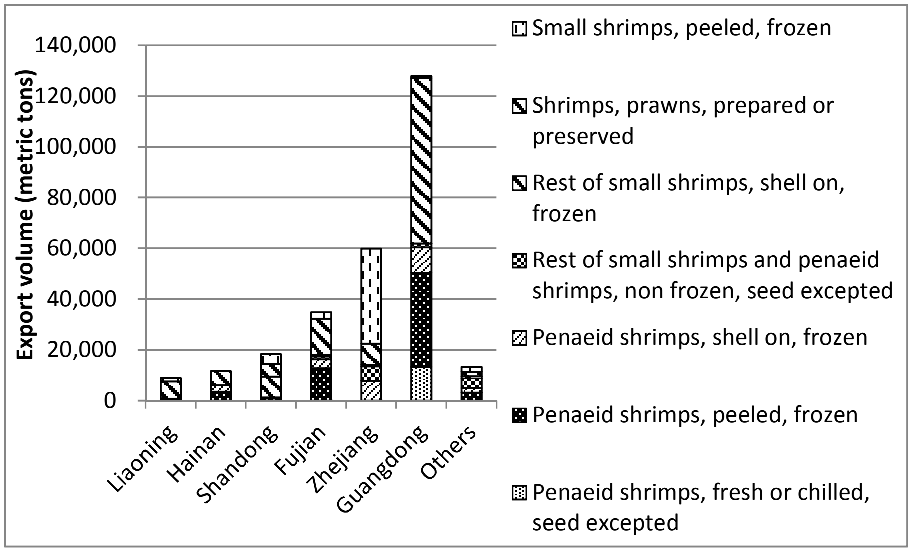


Figure 4.14 Distribution of different shrimp products for export in China in 2010

(Source: China Customs 2014)

Production and export distribution is also concentrated within in various districts in these southern provinces, the so called industrial accumulation area, which is part of government policy to make industry more concentrated and competitive (Table 4.2).

Table 4.2 Concentration areas tilapia/shrimp/prawn production and export

Species	Main aquaculture district (province)	Area (000 ha)	Production (000 mt)	Export (000 mt)	Reference
Tilapia	Maoming (Guangdong)	15	168	40	(Liang & Liang 2009)
Tilapia	Gaoyao (Guangdong)	6.8	82	55	(Yan & Zhang 2010)
Tilapia	Wenchang (Hainan)	8	132		(Hanson *et al.* 2010)
Shrimp	Zhanjiang (Guangdong)	26.6	182	60.3 (2006)	(Zhou & Zhuang 2009) (C. Lu 2010)
Shrimp	Pearlriver delta-Jiangmen, Zhuhai, Zhongshan (Guangdong)	13.3			(Tang 2009)
Shrimp	Beihai (Guangxi)	11.33			(Tang 2009)
M. nipponense	Taihu Lake area (Jiangsu)	124	65.6		(Fu 2007)
M. rosenbergii	Yangzhou (Jiangsu)	11.7	59.2		(Yang *et al.* 2011)

In Guangdong province, the main production areas for both shrimp and tilapia were concentrated in the Leizhou Bay area and the Pearl River delta (Figure 4.15). The Leizhou Bay area, especially Zhanjiang district, was the major location for export of tilapia and shrimp, as well as the centre of shrimp production. Zhanjiang's dominance was explained by its well-developed processing industry and its status as a major container port for export. It also has a relatively large endowment of coastal zone and favourable weather conditions. The most important tilapia producing area was Maoming district, which produced more than 130,000 mt tilapia in 2008. Especially, the Jiangmen, Zhongshan and Zhuhai district in the Pearl River delta, in particular, dominated freshwater whiteleg shrimp farming, but with very low export volume, implying shrimp farmed in freshwater in the Pearl River delta was mainly for domestic consumption.

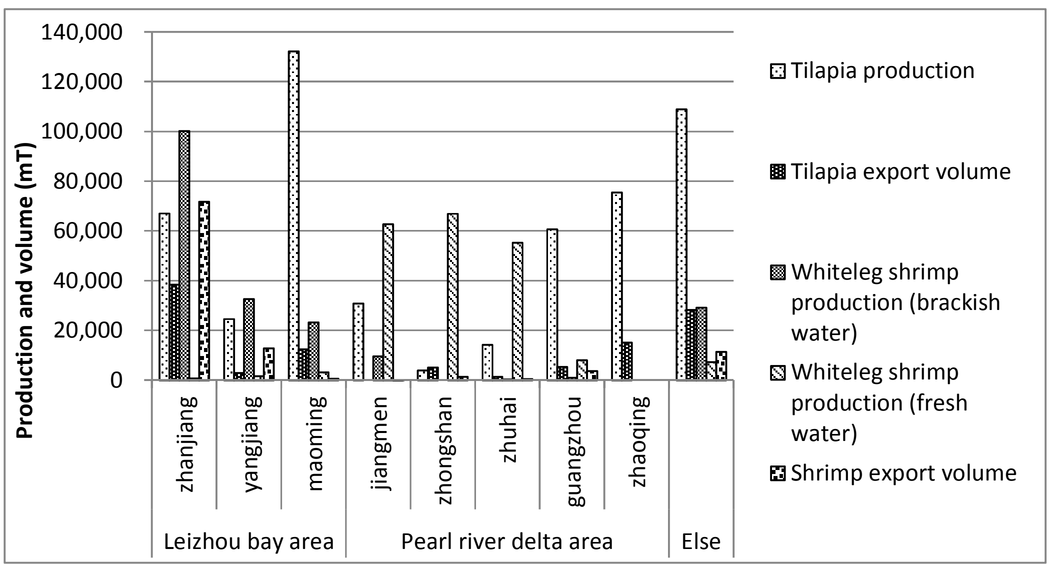
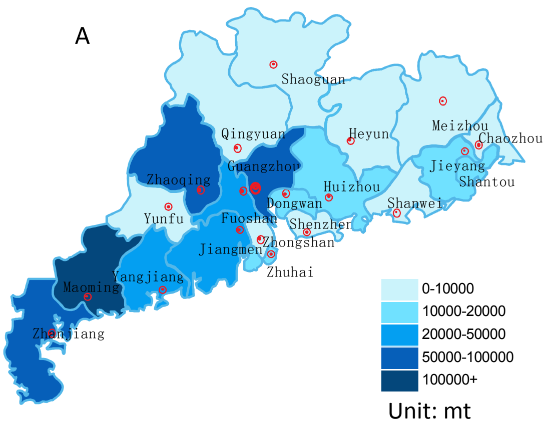
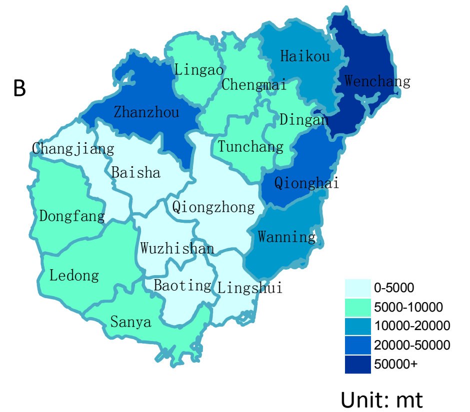


Figure 4.15 Tilapia production, tilapia export volume, whiteleg shrimp production in brackishwater and freshwater, shrimp export volume in Guangdong province in 2008

(source: Oceanic and Fisheries Administrator of Guangdong Provincial 2009, China Customs 2009)

For Tilapia in Hainan Province, the main producing area was the east side of the island, especially in Wenchang area (Figure 4.16). Based on production and export data, the site selected for further research was Zhanjiang district in Guangdong province for whiteleg shrimp. Hainan province and Maoming district in Guangdong province were selected for tilapias.





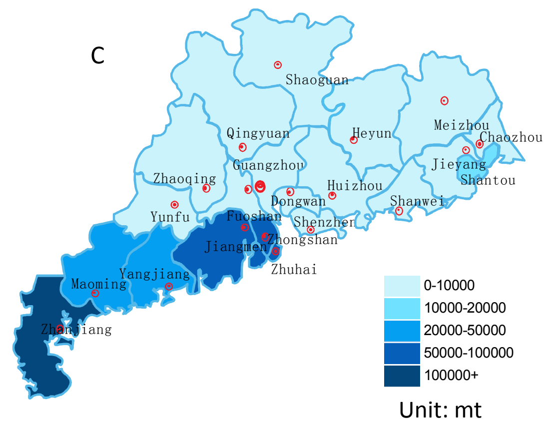


Figure 4.16 Data maps of

A: Tilapia production in Guangdong in 2008

B: Tilapia production in Hainan in 2005

C: Whiteleg shrimp production in Guangdong in 2008

(source: Oceanic and Fisheries Administrator of Guangdong Provincial 2009, China Customs 2009, Oceanic and Fisheries Administrator of Hainan Province 2006)

4.4. Intensification, diversification of culture systems

Following further expansion, the aquaculture sector has intensified and diversified over the past decade (FAO 2010). For shrimp culture in China, as an example, the species diversified from *F. chinensis* dominated shrimp farming in the early 1990s to *L. vannamei* dominating, with smaller quantities of *P. monodon F. chinensis and M. japonicus*. Additionally banana prawn (*Fenneropenaeus merguiensis*), redtail prawn (*Fenneropenaeus penicillatus*) and greasyback shrimp or sand shrimp (*Metapenaeus ensis*) are also farmed in smaller quantitities (Zhao 2007).

Culture systems have also diversified from the original, extensive dyked earthen ponds, to concrete and plastic film lined pond (Lai 2009), and more recently industrialized super-intensive indoor tank systems (Lin 2012).

For tilapias, the species expanded from the original introduction of *O. mossambicus* in 1950s-1970s to Nile tilapia (*O. niloticus*), the hybrids (*O. aureus*♂ × *O. niloticus*♀) and red tilapia (Hanson *et al.* 2010), and the farming system became more diversified (Table 4.3). For Macrobrachium, although only *M*. *nipponense and M. rosenbergii* farming were successful, there were other macrobrachium species trialled (New & Kutty 2010). Other native freshwater prawn species farmed in China, such as *M. hainanense* and Siberian prawn (*Exopalaemon modestus*), were reported by FAO in the category 'freshwater prawns, shrimps nei' with total annual production 13,000 mt and 16,000 mt in 2008 and 2009 respectively (New & Nair 2012). The more diversified culture systems used for *M. nipponense* contribute to its sustainability (Kutty & Miao 2010).

Table 4.3 The main species and culture system of tilapia, shrimp and prawns

Species groups	Major species	Intensification level	Water sources	Containment system
Tilapias	*O. niloticus*, the hybrids (*O. aureus*♂ × *O. niloticus*♀), Red tilapia	intensive, semi-intensive, extensive, integrated with livestock, polyculture	freshwater, brackishwater	earth pond, concrete pond, lake, reservoir, cage, rice field
Shrimps	*L. vannamei, P. monodon*, *F. chinensis, M. japonicas*	intensive, semi-intensive, extensive, monoculture, polyculture, integrated with seaweed	freshwater, brackishwater	earth pond, concrete pond, plastic film lined pond, rice field
Prawns	*M. nipponense, M. rosenbergii*	semi-intensive, extensive, monoculture, polyculture, alternative culture, integrated culture	freshwater	earth pond, lake, reservoir, rice field

Source: (Lai 2009; Kutty & Miao 2010; New & Kutty 2010; Feng *et al.* 2008; Miao 2010; Zhang *et al.* 2011)

The gradually increasing yield per unit area shows a trend towards greater intensification, offsetting a slight decline in the farming area of brackishwater farmed shrimp. Average yield for shrimp increased from two mt ha^{-1} in 2003 to 3.4 mt ha^{-1} in 2009 (Figure 4.17, Figure 4.18). Tilapia production has also intensified; Guangdong produced 389,000 mt tilapia with 50,400 hectare farming area in 2003, and 525,000 mt tilapia with 59,800 hectare farming area in 2006, the average annual yield growth rate was 15% between 2003 to 2006 (Lei *et al.* 2009). Although no farming area data is available for freshwater prawn and *L. vannamei* farmed in freshwater, some studies also reported the intensifying of these species too (Huang 2003; Valenti *et al.* 2007). The reduced farm gate price of shrimp caused by increasing production of *L. vannamei* made the less efficient producers unable to compete with those capable of producing either more cheaply or to produce eco-friendly products (FAO 2006).

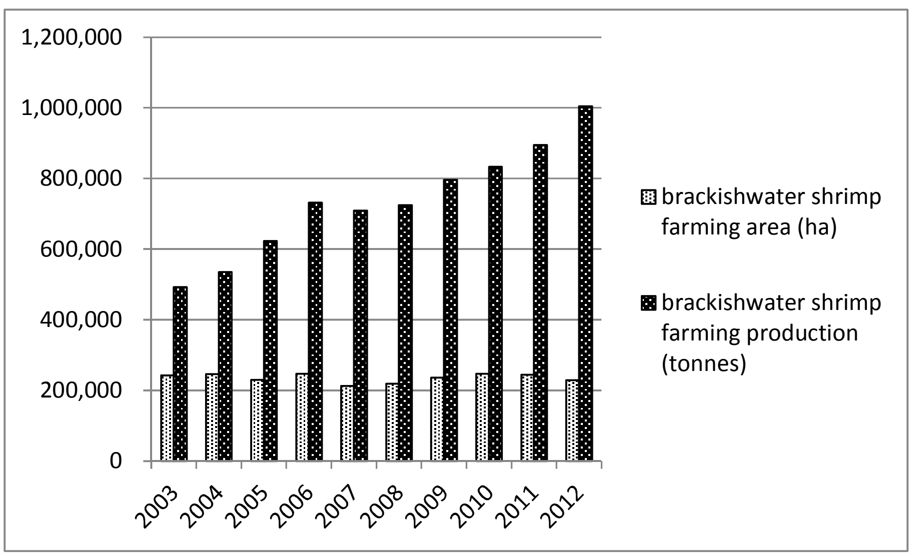


Figure 4.17 Brackishwater shrimp production and area

(Source: MOA 2013)

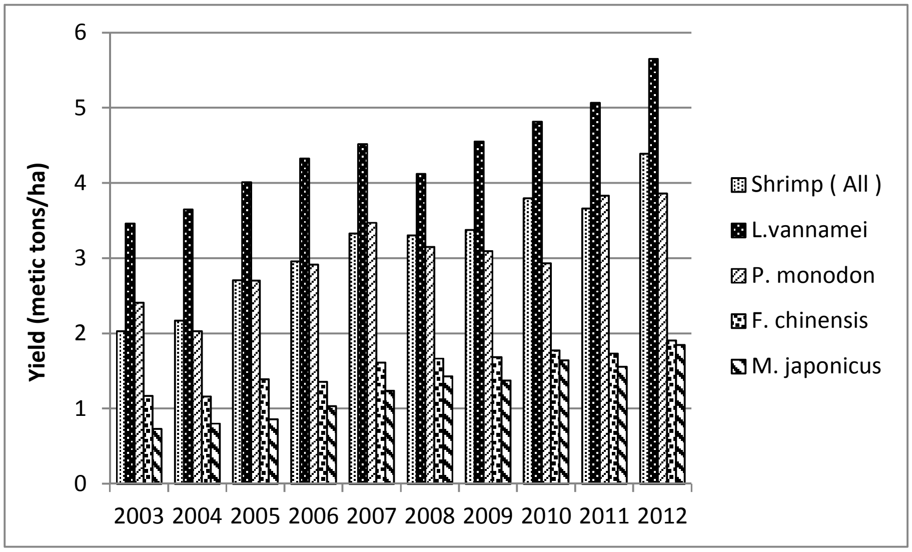


Figure 4.18 Yield of shrimp farming of different species

(Source: MOA 2013)

Among all shrimp species, *L. vannamei* provides the highest yield, related to its fast growth, and is suitable for intensive system and better infrastructure such as concrete pond and plastic film lined pond. These characteristics explain how *L. vannamei* increased both production and farming area compared to other shrimp species (Zhao 2007). Lined ponds used for *L. vannamei*, tended to decline in size compared to earthen pond for more intensified operation (He & Sun 2004). Unlike shrimp, especially *L. vannamei*, freshwater prawn farming cannot be intensified mainly because of their dominance hierarchy behaviour, which has been a key factor in limiting expansion of its culture (New 2010), but the intensification of *M. nipponense* was seen as a solution to meet domestic consumption needs (Kutty & Miao 2010).

China's aquaculture remains largely a small-scale enterprise. For example, the farm size of *M. nipponense* farms ranged from 0.4 to 2 ha (Kutty & Miao 2010), while 50-70% of *M. rosenbergii* farms are less than one ha in area; only 5 to 10% are over five ha (New & Kutty 2010), although the proportion of total production from larger scale farms maybe higher.

4.5. Foundation - seed and hatchery development

Closing the life cycle of a species is essential for seed improvements, a key factor in aquaculture success (Little 2004; Nguyen & Dang 2010). The tilapia, shrimp and prawn seed industry in China has, alongside the development of culture, been growing fast and building a solid foundation for the whole value chain.

In China, hybrid tilapia and new strains of Nile tilapia have been broadly embraced, especially New GIFT and the hybrid tilapia *Ao-Ni* hold a leading position in tilapia culture, and are supporting progress for the whole industry (Guangdong News 2010). The initial spread of the tilapia industry was slow and constrained by poor cold tolerance, early maturation and high fecundity leading rapidly to overpopulation of the aquaculture system as well as small size and slow growth (Lai & Yang 2004). After several introductions of the cool tolerant *O. aureus* in 1981 and 1983, the hybrid *Ao-Ni* with a higher male proportion started expansion in the middle of 1980s, becoming the main farming species (Ye 2008). The Nile tilapia and Gift strains were introduced for their fast growth character, and blue tilapia, originally for its high male ratio when crossed with *O. niloticus* to produce hybrid tilapia. Although the growth rate of GIFT was faster than that of hybrids (Mo & Lin 2010; Ye 2008), the improved cool tolerance of hybrids compared to pure Nile tilapia was a major advantage that was realised during the unusually cold winters in 2008. In 2004 it was estimated that as much as 60% of tilapias produced were hybrids (*Ao-ni*) (Gupta *et al.* 2004), but according to more recent reports, the proportion of Gift strain has increased and already surpass the *Ao-ni* tilapia (Guangdong News 2010). In the latest FAO statistics, 75% tilapia produced in China was Nile tilapia, and 25% Blue-Nile hybrid (FAO 2014b).

Seed production remains inconsistent for tilapia shrimp and prawns (Figure 4.19). Tilapia hatchery output varied from 20 billion to 30 billion in recent years, although this did not appear to impact negatively on grow-out, seed supply has remained restricted especially in 2010 and 2011 due to unstable weather (Aquaculture Frontier 2010b; Zeng 2011a).

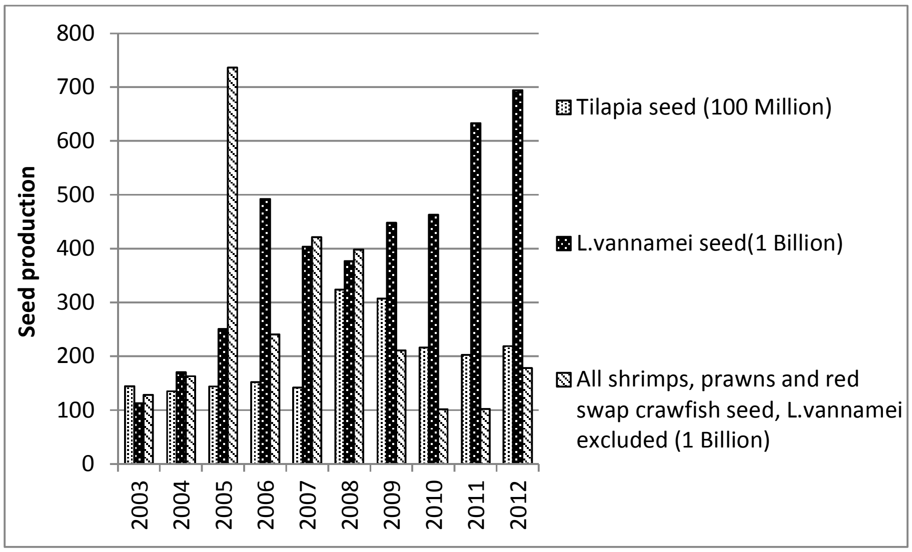


Figure 4.19 Annual seed production of tilapia, whiteleg shrimp and all shrimps, prawns and red swamp crawfish seed with *L. vannamei* excluded

(Source: MOA 2013)

Successful artificial breeding of fleshy prawn (*F. chinensis*) in the 1980s was an important milestone in China's shrimp farming industry (Li 2007). Shrimp hatcheries also provide enough seed for farms, but the dependence on imported broodstock of *L. vannamei* (Briggs *et al.* 2005), has become a major constraint for the whole industry (Zhou 2010).

Artificial breeding and larval rearing technology of the two Macrobrachium species for large-scale commercial production has been established with annual postlarvae (PL) production of approximately 20 billion and 30 billion of *M. rosenbergii* and *M. nipponense* respectively (Fu *et al.* 2012). The *M. nipponense* larvae mainly rely on natural reproduction in the culture water body, and growth of species has thus possibly been constrained by a dependence on self-recruitment and inbreeding (Feng *et al.* 2008; Kutty & Miao 2010), but wild-caught PL and juveniles are rarely used due to difficulties of transportation and low survival (Kutty & Miao 2010). In contrast, the *M. rosenbergii* larvae derive from commercial artificial hatcheries for which production remains inconsistent (Kutty & Miao 2010; New & Kutty 2010). New stock of *M. rosenbergii* were introduced through various countries for improving the seed quality in 2001 and 2002 (New & Kutty 2010). Although domestic PL supply is reported to be adequate for exceeding demand, and total seed production was estimated to have reached over 26 billion year^{-1} by 2007 (New & Kutty 2010), the failure of prawn hatcheries in providing enough seed for *M. rosenbergii* farming has been linked to genetic degeneration, bad weather and diseases in 2010 and led to big losses for the whole *M. rosenbergii* industry (Pan & Xu 2010). Seed quality remains a problem for the industry and more new stock were introduced recently, included the patented all-male *M. rosenbergii* introduced from Israel in 2012 (Lv 2013).

No official data about hatcheries exists, according to publications, there are more than 200 tilapia hatcheries and nurseries including five national fine seed hatcheries and more than 10 famous tilapia seed brands, can produce more than five billion juveniles every year, the tilapia hatcheries and nurseries are located mainly in Guangdong (100), Hainan (40) and Guangxi (10) (Ye 2008). According to estimation, there are 2,500 shrimp hatcheries and nurseries, and 120 prawn hatcheries and nurseries in China now (Yang 2008; Li 2011). Shrimp and prawn hatcheries and nurseries are also concentrated in the main producing areas. For example, in Zhanjiang district of Guangdong province, there were 431 shrimp hatcheries and nurseries in 2007 providing 50 billion shrimp fries every year (Li 2008). Seed productions is generally distributed in the main farming areas (Figure 4.20), the tilapia seed produced mainly in Guangdong, Hainan and Guangxi, the *L.*

vannamei seed produced mainly in Fujian, Guangdong, but seed production of all other species of shrimp, prawn and crawfish was mixed, mainly in Liaoning, Fujian, Zhejiang and Hubei. Liaoning, as one of earliest shrimp farming and seed producing area, mainly produced seed for *F. chinensis*, Hubei mainly produced seed for red swamp crawfish, and Zhejiang is well known for *M. rosenbergii* seed.

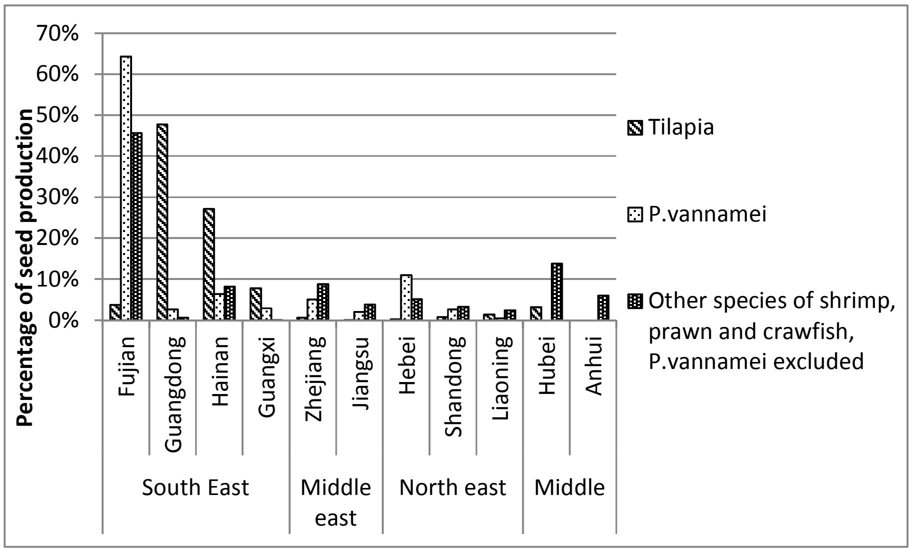


Figure 4.20 Percentage of seed production in the main producing provinces in 2012

(Source: MOA 2013)

High quality strains of the exotics *M. rosenbergii, P. hypothalamus*, SPF *L. vannamei* and tilapia are now certified and a variety of new species and varieties of tilapia (4) and shrimp (5), although no new varieties of Macrobrachium have yet been certified (NCCAV 2011). The main criteria for selection under this for this standard is an improved growth rate, except for the *Zhongxin* No.1 strain of *L. vannamei* which has resistance to White Spot Syndrome Virus and *Ao-ni* tilapia for it's high male ratio (NCCAV 2011). More selection or hybrid programs for tilapia, shrimp and prawns are now ongoing such as *JA* tilapia (NEW GIFT strain *O. niloticus* ♀×*O. aureus* ♂) (Chen *et al.* 2008) and *Huanghai* No.2 strain of *F. chinensis* (Anonymous 2010), to support efforts towards more intensified and diversified farming systems.

4.6. Industrialization and modernization- feed, chemical and other inputs

Intensification and diversification of farming system require more and higher quality inputs, particularly formulated diets (Miao & Liao 2007; Hasan *et al.* 2007). Feed development is critical for farming, especially for some species such as shrimp (Miao & Liao 2007). Shrimp and tilapia farming are the second and third largest aquafeed consumers in the word, accounting for 18.1% and 9.5% total world aquafeed consumption respectively (FAO 2009b).

China is the world's largest producer of industrial compounded aquafeeds, with more than 10,000 aquafeed mills producing 8.0 mmt aquafeeds annually and 40%-45% of farmed fish are fed on them (Miao & Liao 2007). In China, freshwater carps and tilapias are the biggest consumers of commercial aquafeed followed by shrimp (Miao & Liao 2007). Species specific data for tilapia, shrimp and prawn feed are not officially published, but estimates suggest that in 2006, China produced 65,000-1,440,000 mt shrimp feed and 75,000-1,500,000 mt tilapia feed (Tacon & Metian 2008). Another estimate based on tilapia production suggests that more than one mmt tilapia feed are produced every year (Yang 2010). The development of pellet feeds with high protein levels was the key factor for shrimp farming (Xie & Yu 2007), in contrast to tilapia for which poorer quality feeds were appropriate (Hanson *et al.* 2010). FCRs for shrimp vary between 1.2 to 1.6 : 1 (Miao & Liao 2007), with the best attaining 1.0-1.2 (Li 2008), while for tilapia is 1.2-1.5 for floating pellet feed and 1.5-1.8 for sinking pellet feed (Liu, 2008) is normal and between 2.0-2.31 for *M. rosenbergii* (New & Kutty 2010).

According to Miao & Liao (2007), farm-made feeds remain important for some species (Miao & Liao 2007), especially for species cultured at low intensity, such as *M. rosenbergii a*nd *M.*

nipponense (Kutty & Miao 2010; New & Kutty 2010). Formulated diets are more commonly used by larger prawn farmers and those producing *M. nipponense* as the major species (Kutty & Miao 2010).

More frequent and serious diseases have affected tilapia and shrimp in recent years, especially *Streptococcus* infections for tilapia and various diseases for shrimp (Liu 2011b; Chang & Zeng 2011). Tilapia farming previously required few medicines but the onset of increasingly severe *Streptococcus* infections since 2009 (M. Lu 2010) has led to widespread use of various chemicals (Rico *et al.* 2013). Shrimp diseases mainly viral, had no effective treatments but increasingly shrimp farmers are seeking bio control using probiotics to improve the pond environment (Li *et al.* 2009). Compared with shrimp and tilapia farming, the low intensification level of macrobrachium farming has needed less chemical input, and when integrated with rice farming can even lead to reduces chemical using in rice culture (Kutty & Miao 2010).

4.7. Processing

Tilapia processors are limited to processing farmed tilapia and are mainly located in south east China, especially in Guangdong and Hainan province. There are around 120 processing plants producing tilapia products of which 30 of them specialise in the species (Wang *et al.* 2010). But shrimp processors process both wild and farmed shrimp; most processors located in Zhejiang province and Shandong Province process wild shrimp, and those in Guangdong and Hainan mainly farmed shrimp (Figure 4.21).

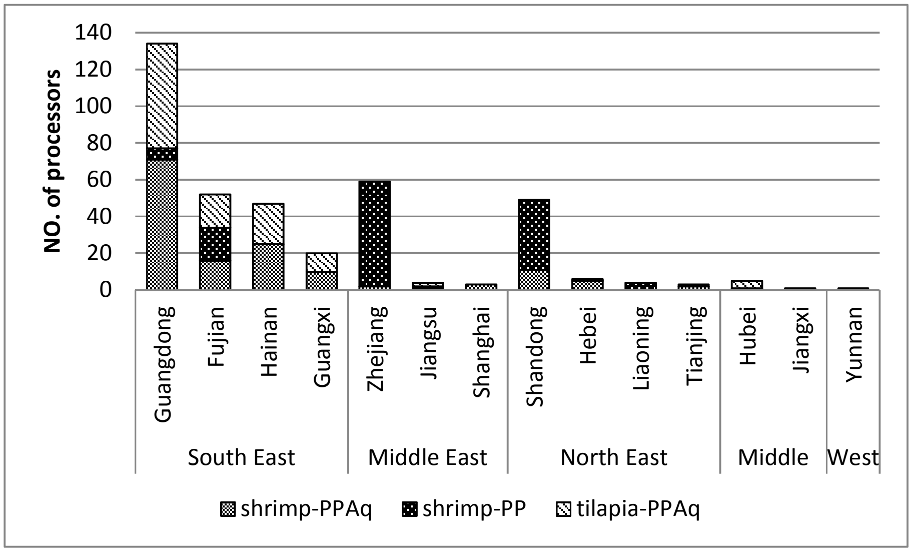


Figure 4.21 Number of China enterprises produced tilapia and shrimp products approved by EU and US in 2010

(PP: Processor plant, PPAq: Aquaculture product (farmed product) included) (Source: EU commission 2010; CNCA 2010)

4.8. Export markets and domestic consumption

North America still remains the major export market for Chinese tilapia products with US and Mexico being first and second, respectively, in terms of importance. The EU is now the third largest and is expected to be the fastest market in the future (Hanson *et al.* 2010). Concentrations of Asians, usually in cities, were the major consumers in the early years of tilapia imported into the US. Imports then accelerated as the Tilapia Marketing Institute (TMI) in US promoted a strategy of no differentiation between US and foreign tilapia products (Josupeit 2005) and the collapse of wild-caught stocks such as the Atlantic cod occurred (Einhorn 2010). Tilapia was embraced as a welcome substitute for its affordability, mild flavour, and ubiquity (York 2011) and has become mainstream choice in retail and food service, endorsed by nutritionists (Young 2009; Coffman 2014) and high profile consumers, such as Michelle Obama (Fitzsimmons & Hong 2011). Whereas Vietnams' striped catfish exports to the US fell foul of the lobbying power of the domestic catfish industry, and suffered a series of anti-dumping and labelling challenges (De Silva & Phuong 2011), the lack of any large-scale domestic tilapia farming industry and US investment in overseas production had no equivalent challenge. Domestic tilapia farming in the US targets live tilapia sales to differentiated high price, niche markets (Fitzsimmons 2011a). Although experts expected a decline in tilapia consumption in the US during the economic crisis and food service sales did decline slightly, more tilapia were sold in grocery stores supporting an overall increase in consumption (Fitzsimmons *et al.* 2009). Now tilapia is firmly established as an accepted product, opportunities for meeting local live tilapia at a premium are growing, such that US produced tilapia has attained a 10% average growth rate since 2000, reaching 53,886 mt in 2011 (FAO 2012a). The same phenomenon has been predicted, but remains unrealized, for Europe (CBI 2011).

Compared to the US, Europe remains a relatively small importer of tilapia. Consumers remain more "old-fashioned" in the preferences, with diets characterised by traditional species such as herring, salmon, cod and pollack. Critically also, striped catfish entered the market during the same period and established itself in the same niche (CBI 2011; Bolla 2011); striped catfish accounted for 90% of the imported freshwater fish in the EU (FAO 2012b). EU consumers perceive tilapia as exotic and lack knowledge of the product, its origin and culture and, especially, its preparation in the kitchen. At the same time, tilapia often comes from small producers where there is a lack of interest in, and knowledge of, promotional techniques. The African, Chinese and Asian communities in big European cities consumed most imported tilapia, mainly as whole or gutted, but the consumption of tilapia in non-ethnic markets increased recently (Josupeit 2005), especially of value-added products (CBI 2011). The European market is more concerned about standards of production in terms of ethics, sustainability, traceability, sourcing of feed ingredients especially the use of GMOs and fishmeal, worker and animal welfare, genetics in shrimp breeding and irradiation (CBI 2011; Briggs *et al.* 2005). In 2012, Europe imported over 36,700 mt of tilapia and the future for tilapia imports seem to be stable, partly explained by its less tarnished reputation, but also higher price compared to imported striped catfish (CBI 2013c).

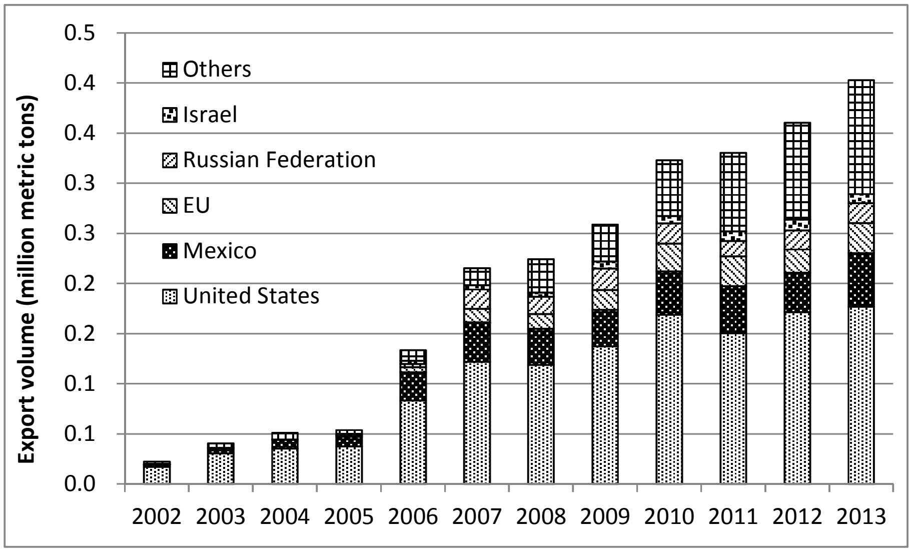


Figure 4.22 Major tilapia export markets

(Source: China Customs 2014)

Compared to tilapia, shrimp export markets are more diversified. Asian countries and territories imported half China's shrimp export products, while the US and EU are the no.1 and no.2 markets.

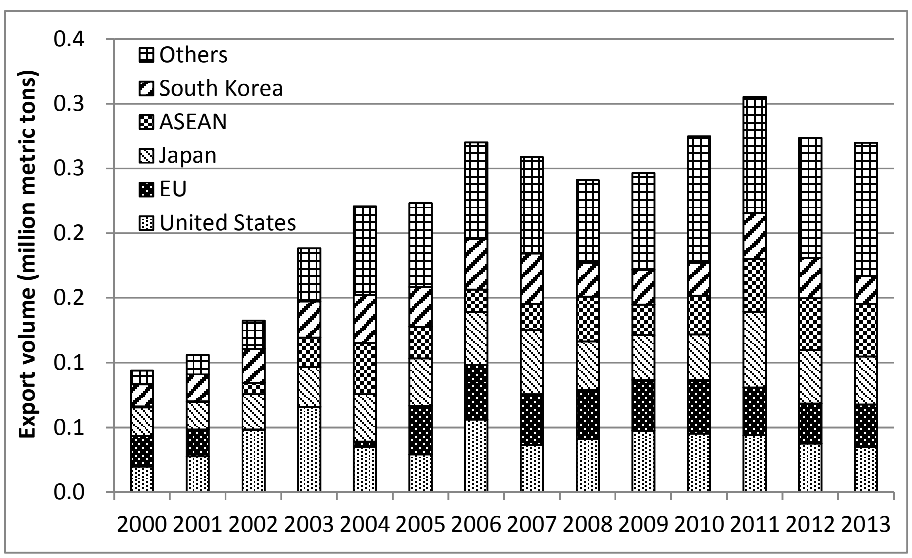


Figure 4.23 Major shrimp export markets

(Source: China Customs 2014)

However, if shrimp products are differentiated by wild sourced/farmed and other qualities (Table 4.1), huge differences in market preferences have emerged. EU and Japan were the major markets for wild shrimp products, accounted for more than 50% and 20% of total wild shrimp export in the recent years (Figure 4.24). This also reflects the “old-fashioned” conservative character of EU market, which more favour traditional wild capture products.

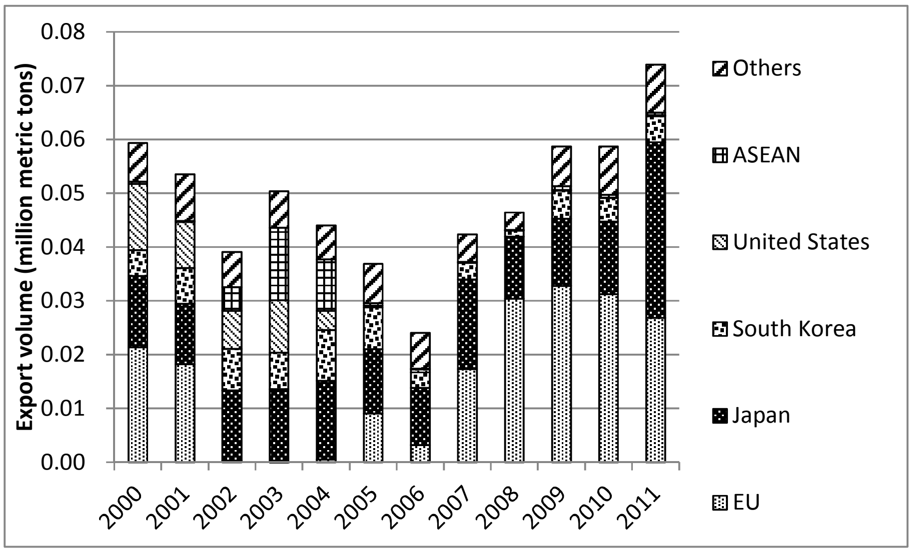


Figure 4.24 Major wild shrimp products export market

(Source: China Customs 2014)

Along with the rapid export volume growth of shrimp and tilapia the number of importing countries also increased. This trend was particularly rapid for tilapia with the number of countries importing tilapia and shrimp from China growing to 87 and 80 respectively by 2010 (Figure 4.25). The diversification of international markets was seen as being a major driver for the rapid growth of the striped catfish farming sector in Vietnam (Bush *et al.* 2010). Hanson *et al.* (2010) predicted that traditional tilapia export markets would remain stable, and new growth associated with penetration into new markets.

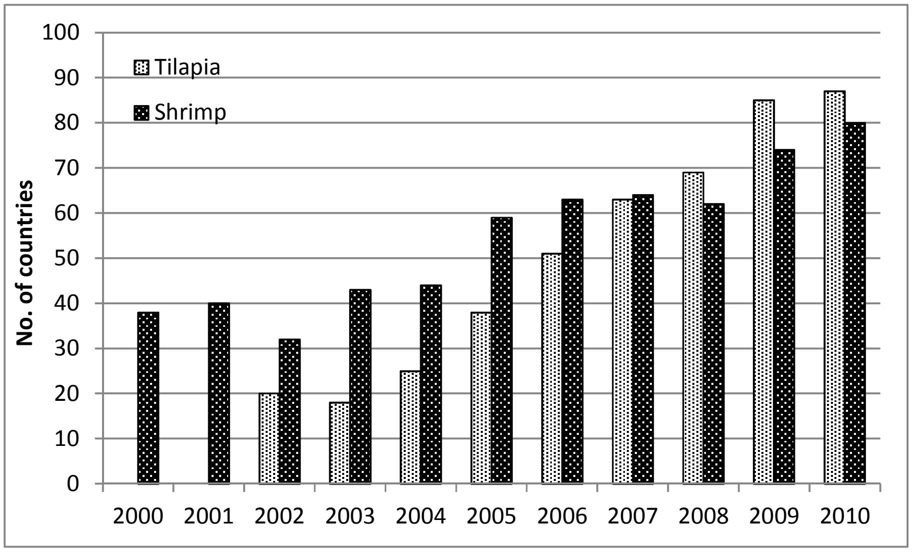


Figure 4.25 Number of countries importing tilapia or shrimp from China during the year 2000-2010

(Source: China customs 2011)

The supply balances for fish and fishery products can be calculated in "live weight equivalents" (Paquotte *et al.* 2008). After processing, the weight of tilapia fillets remains approximately 36% (average 35.7% with large differences between strains range 34.4–38%) of whole fish (Rutten *et al.* 2004) and the shrimp tails constitute around 65% of whole shrimp weight (Argue *et al.* 2002). After excluding the wild shrimp export and assuming prepared or preserved tilapia products are fillets and that prepared or preserved shrimp are tails, more than half of tilapia and 21% of farmed shrimp in China were exported in 2010. Although this may not be accurate for some exported shrimp products that were derived from wild capture, there still appears to be a clear trend towards higher domestic consumption of shrimp and export of tilapia. The trends show that exports of whole shrimp equivalent volume peaked in 2006, and then declined, especially in 2008, contrasting with steady and strong growth of domestic shrimp consumption. For tilapia, the domestic consumption remained stable, the growth of tilapia mainly supplying the international market, just as the expansion of Vietnam striped catfish export stimulated the industry's development (Nguyen & Dang 2010).

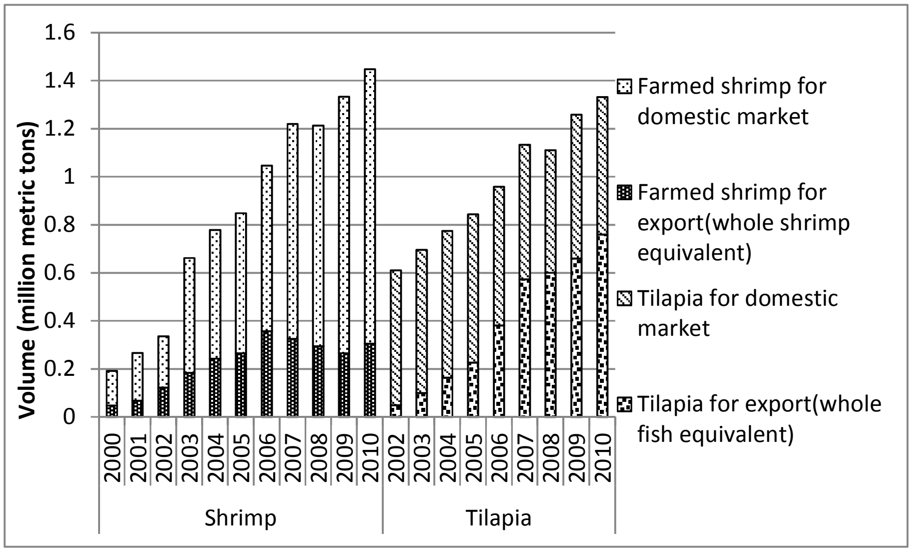


Figure 4.26 Extrapolated proportion of tilapia and shrimp exported and consumed domestically

(Source: China customs 2010; MOA 2012)

Chinese prefer live fish to processed, but marketing live is relatively costly-especially at distance. Recent seafood consumption survey also found most of fish in domestic market were local sourced (Chiu *et al.* 2013). This has restricted domestic tilapia consumption mainly to the southern provinces, closer to its site of production (Bean & Wu 2006; Hanson *et al.* 2010). Besides, tilapia is considered similar to carps in terms of taste and texture, and demands a similar price. Although processed frozen fillet has no such problems (Hanson *et al.* 2010), and tilapia fillets are available in supermarkets and some marketing is underway in large cities, consumer acceptance remains low (Bean & Wu 2006; Chiu *et al.* 2013). Lessons learnt from elsewhere, principally North America and Europe, regarding cold chain management suggest trends towards eating less live marketed seafood are likely and more towards convenient form for urban, industrialized life styles. Such trends are aligned to China's new policy for stimulating domestic consumption and it is expected that the domestic consumption of tilapia will likely increase over time (Hanson *et al.* 2010).

Farmed shrimp export growth returned in 2010, probably driven by the recovery of the world economic situation and historically high farmed shrimp production. Meanwhile, both farmed and wild shrimp recorded growth of imports (>50% in 2010), especially of farmed shrimp, while the wild shrimp exports remained stable (Figure 4.27).

International shrimp prices reached record heights in 2013 mainly caused by the EMS (Early mortality syndrome) and fast rises in demand from China, which changed European buyers from price leaders to price followers (CBI 2013b).

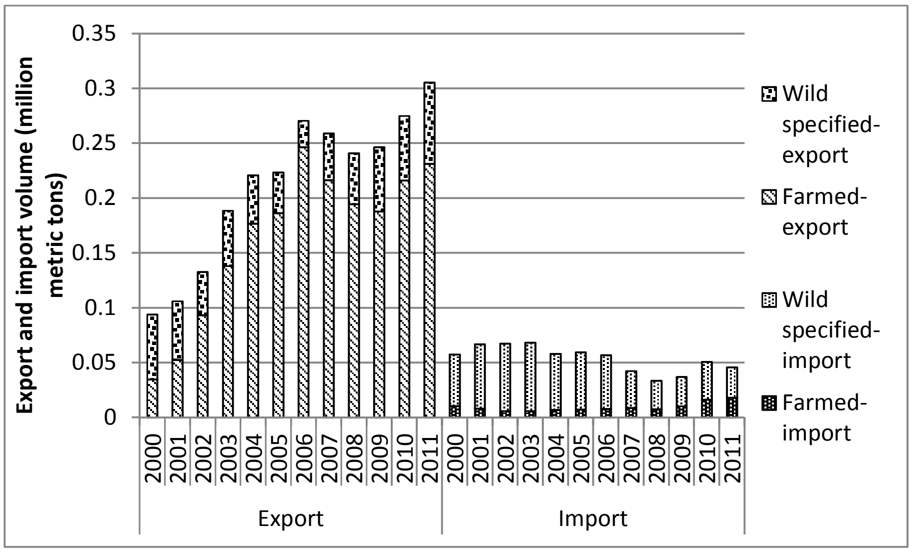


Figure 4.27 Wild and farmed shrimp import and export by in China

(Source: China Customs 2014)

For shrimp imports, if wild shrimp were excluded, growth rates accelerated since 2008, and more than 80% were imported from ASEAN countries in 2010, as one of the positive results of the ASEAN-China tariff reducing plan.

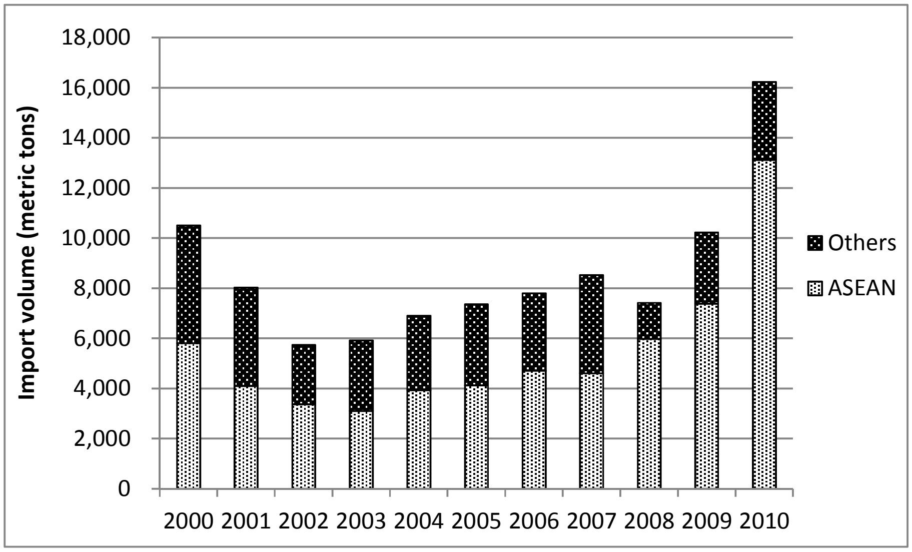


Figure 4.28 Import of farmed shrimp in China

(Source: China customs 2011)

As China's economy has flourished in recent years, the proportion of shrimp for export has reduced significantly accompanied by accelerated shrimp imports, it is predicted China's shrimp consumption will surpass production in the coming years, and will promote a new cycle of worldwide shrimp production increase, but the shrimp exporting maybe will not stop, and more shrimp will be imported especially from ASEAN countries (Cui 2011).

4.9. Stakeholders and value chain

The main local stakeholders (in-country) include both primary and secondary stakeholders. Primary stakeholders include feed companies producing and marketing feeds and drugs/chemicals, broodstock producers and/or providers/importers, hatcheries and nurseries, grow-out farms, processors, exporters, local traders, local market, and domestic customers. Secondary stakeholders include several sub-categories such as facility support providers, service and infrastructure providers, support providers, inspectors, and stakeholders affecting or affected by aquaculture (Table 4.4).

Table 4.4 Subcategories of secondary stakeholders

Inspector	Facility provider	Service and Infrastructure provider
CIQ, DOF	Aerator factory	Machine maintenance
Customs	Aquaculture facility	Well construction
	CO factory	Building constructer
Support provider	Container factory	cold storage
Bank	Bait-casting machine	Feed/Chemical Shops
Insurance Company	Gauze mask factory	Feed/Drug technique service man
Local/Central government	Generator factories	Porter (bearer) team
University/Institutes	Glove factory	Harvesting team
Local village committee	Ice factory	Local market
	Building material	Material Importer/Dealer
Affecting or affected by	Fuel	Middle man
Tourist industry	Machine factory	Pond digger/builder
Catering trade	Net factory	Sediment removal team
Fish farm neighbours	Packaging factory	Servicer of fish disease diagnosis
People using water from farm to irrigation	Piper factory	Transportation
Fish thieves	Plastic Film company	Water quality test/ improve
Industrial pollution (glass factory, alcohol factory)	Pump factory	Power station
Watchdog	Test Instruments Company	Road construction
Foreign customers	uniform manufacture factory	Water supply
Domestic customers		Weather Station

(Source: Zhang *et al.* (2011))

Based on the relationships of stakeholders, the value chain was presented as a flow chart (Figure 4.29). The value chain was split sharply into two parts by the China Entry-Exit Inspection and Quarantine Bureau (CIQ) export-oriented registration system (AQSIQ 2004). CIQ standards only referred to the farm itself and did not control up or downstream activities or require specific biosecurity measures. The registration system prescribed that all farmed seafood going for export must have come from registered farms, and only farms of a certain size (>3.3 ha for earth ponds or >0.66 ha for concrete ponds) could be registered (AQSIQ 2004). In effect this led to smaller scale producers being excluded from export markets. Most registered tilapia farms used polyculture in ponds and, to a lesser extent in reservoirs. In contrast, non-registered farms often integrated fish and livestock production. There appeared to be less difference between registered and non-registered shrimp farms. For processors, the CIQ registration also was necessary for seafood export. Another key difference between the tilapia value chain and shrimp industry was the continued reliance on imported Specific Pathogen Free broodstock from shrimp hatcheries in Hawaii (Zhang *et al.* 2011).

Along with the rapid development of the aquaculture industry, some vertically integrated enterprises have emerged. Companies such as Tongwei, Evergreen and Guolian have implemented an operational model based on the concept of linking "companies + bases + farmer households", that provide feed, seed and technical support to farmers. The approach involves monitoring the farming process throughout the culture cycle, and purchase of adult fish/shrimp from farmers after harvest (Figure 4.30). Through the close control of the whole value chain intrinsic to the model, the enterprises have more power to extract profit and have more opportunity to ensure full traceability, particularly with regard to food safety. Although these enterprises currently make up a minority share of the market, they are expanding rapidly and could potentially drive upgrading of the whole industry.

Direct administration of farmed seafood products in China was divided between different line agencies, including the Ministry of Agriculture (MOA) and the General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (AQSIQ). These organisations were represented at national, provincial, district and county levels (Figure 4.31).

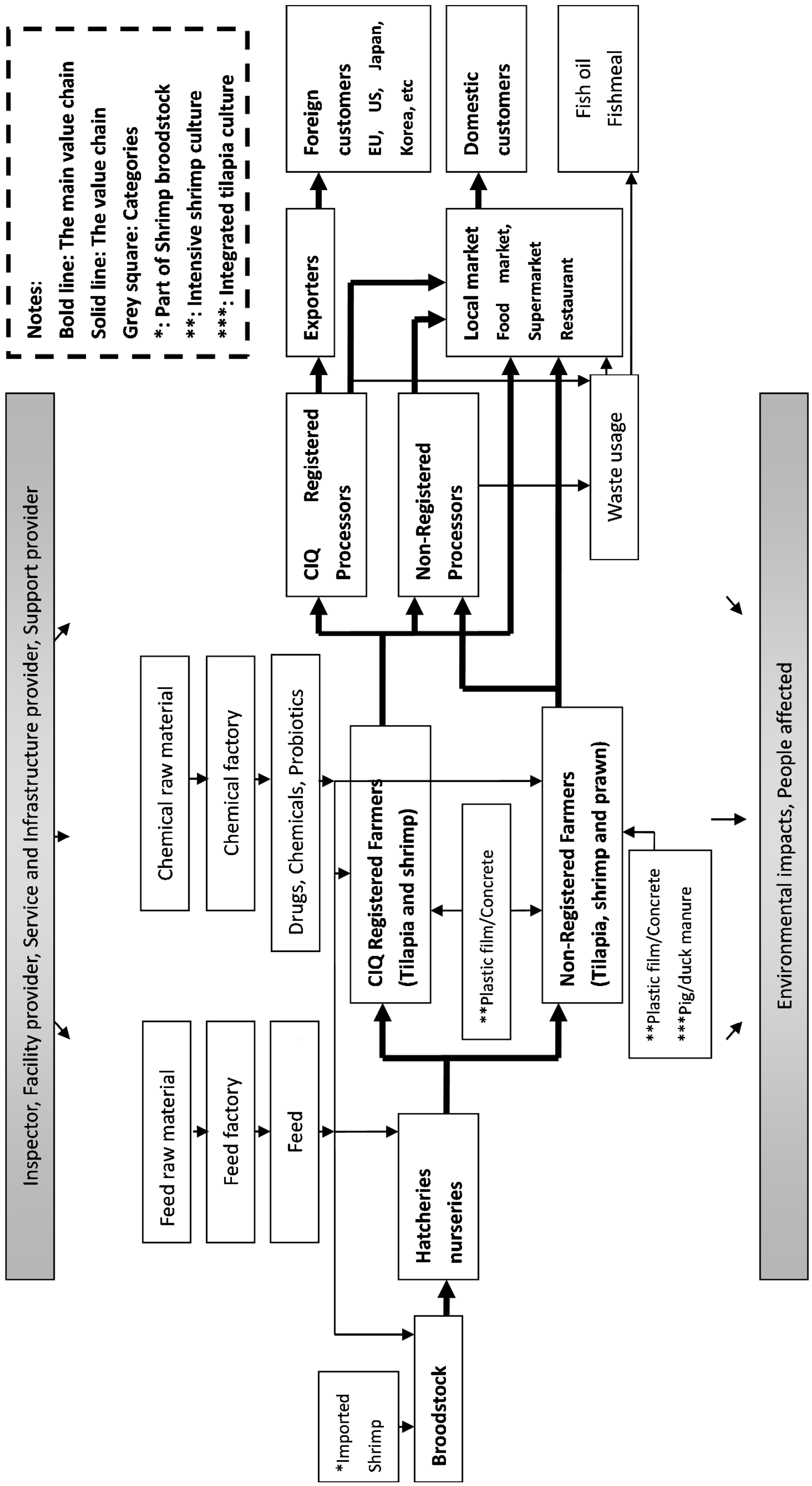


Figure 4.29 Flow chart of farmed shrimp and tilapia value chains

(Source: Zhang *et al.* (2011))

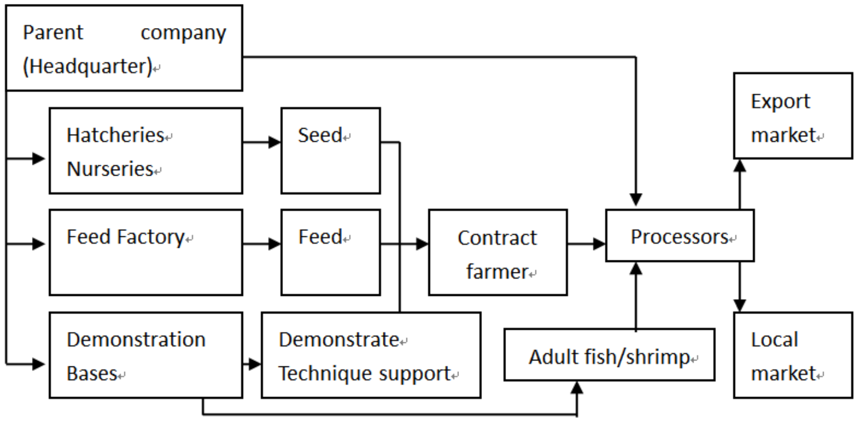


Figure 4.30 Vertical integrated value chain

(Source: Zhang *et al.* (2011))

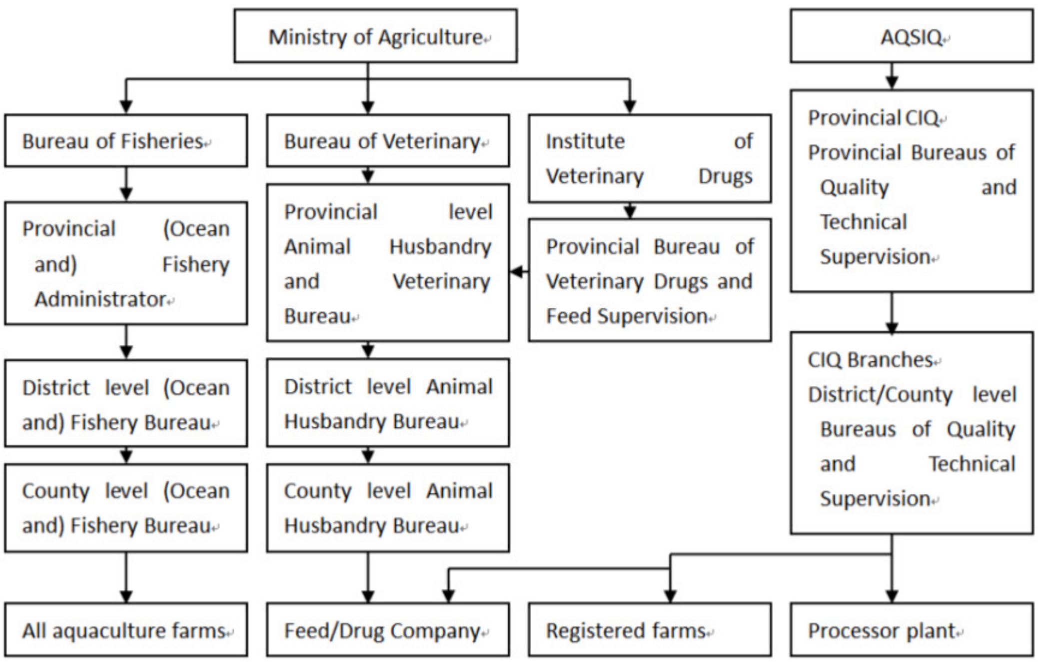


Figure 4.31 Hierarchy and administrative affiliations of administrations of farmed seafood products in China

(Source: Zhang *et al.* (2011))

4.10. Discussion

China is the leading producer of tilapia, penaeid shrimp and macrobrachium prawns, and the leading exporter of tilapias and shrimps, while macrobrachium prawns mainly provide for domestic market and striped catfish is not produced commercially (FAO 2012a; FAO 2012c). The production expansion of these species is characterized as soaring production for tilapias and shrimps especially for *L. vannamei* in both brackishwater and freshwater, in contrast with slow growth and even reduced production of other shrimps such as *P. monodon*, *F. chinensis* and *M. japonicas*, and steady and slowly increasing production of freshwater prawns, while the production of striped catfish failed in try-out. Behind different development status and trends of these species, there are the differences in the biological characteristics of the species, market demands and the suitability for these species for intensification and diversification to meet demand. For striped catfish, particularly, the climate conditions were the main constraint to its expansion in China.

Sustainability and economics in aquaculture both depend on ecological efficiency, i.e., the use of resources and the production of waste, species feeding low in the food chain use the natural resources more efficiently (Neori & Nobre 2012). Aquaculture species and farming systems with higher efficiency and lower costs are more likely to dominate (Muir 2005). Good farming species must deliver an appropriate balance of economic, social, and ecological benefits, such as economic returns, market demands, and ecological efficiencies (Wang 2000). At the same time farming species should possess particular biological characteristics, such as quick growth, low trophic level, being euryphagous, have ability to reproduce and simple culture of the juvenile fish, high resilience, and availability in natural bait or artificial feed (Carballo *et al.* 2008; Wang 2000). Just as herbivorous cattle and sheep, and the omnivorous pig dominate the livestock industry, aquaculture production is dominated by species that feed at the lower levels of the food web, such as carps, tilapias, molluscs and seaweeds (Li 2003). Species at low trophic level, together with conditions such as marketability, easy reproduction, fast growth and hardiness make them cheap and can be produced in large volume, and have an advantage in entering new markets and in reaching a high-level of production (Neori & Nobre 2012). Species that will be produced in large volume are those where the potential for productivity growth is largest and where production cost can be the lowest (Asche *et al.* 2008).

The success of tilapias and *L. vannamei* was related to their relatively high ecological efficiency, low trophic level, and soring market demand in domestic and international market. Species like tilapia, which can be grown semi-intensively with far less complex and demanding resource inputs than those for marine carnivores, may have much more potential, and may offer important international trading opportunities, particularly for developing countries (Young & Muir 2002; Muir 2005). *L. vannamei* has some competitive advantages over other penaeid shrimps, such as faster growth rate, safe high stocking density, low salinity tolerance, cool temperature tolerance, less feed protein requirements and possibility of breeding and domestication and less disease (Bondad-Reantaso *et al.* 2012).

Intensification of shrimp farming in brackish water areas requires high-level management to ensure adequate biosecurity, as disease is still ranked as the major constraint by shrimp farmers (see Chapter 6). The recovery of the shrimp industry from its low point in the early to mid-1990s has been on the back of introducing the exotic *L. vannamei*, and the pathogen free broodstock imported at high cost from overseas. Building self-sufficiency in broodstock and capacity for selective breeding gains is a key objective for the larger vertically integrated enterprises that are in the business. However, shrimp broodstock selection still has a long way to go because it remains very costly and time-consuming (Current Fisheries 2011). Because the shrimp industry in China is more diverse and has a lack of leading companies, most of hatcheries still are small-scale and only account for small proportion of market share (Lin 2013). It is reported that the Charoen Pokphand (CP) company, a vertically integrated major firm, had played a major role in the establishment of *P. monodon* and *L. vannamei* farming in Thailand (Lebel *et al.* 2010), and China started to import *L. vannamei* broodstock from CP company in Thailand in 2013 (Lin 2013).

The farming systems of tilapias, shrimps and prawns in China can be characterised as developing towards intensification and diversification, primarily because of competition and diverse market demands, with increasing stocking density and input in general, and more farming species and farming systems at different intensification levels. Intensification is important for smaller scale farms to be economically viable and sustainable, which was traditionally linked to population pressure (Little & Edwards 2003). Although the most intensively produced species are also among the most valuable (Asche *et al.* 2008), low intensification level of macrobrachium prawns have developed due to diversified market demand. Tilapias and *L. vannamei* proved their potential for intensified farming systems featuring high input and yield but prawn farming remains viable at a lower intensification level because of strong local demand and growing interest in credence qualities, some of which may be peculiar to China or at least East Asia (Chen *et al.* 2001; Ge *et al.* 2013; Josupeit *et al.* 2001; Xie *et al.* 2013).

Besides these biological characteristics, different development status shows the climatic condition is an even more important factor for aquaculture species (Nath *et al.* 2000). The relative productivity development determines where production takes place, both between and within regions (Asche *et al.* 2008). In south China, *L. vannamei* farming can get two farming cycles per year with production around 7.5-15 mt $ha^{-1}cycle^{-1}$, while in north China only a single crop is possible (Wang *et al.*, 2005). Indeed, production and processing are clustered in a single province and, in a relatively limited geographical area. Much of this can be explained by geography in that the more southern coastal areas of the country have a better climate for raising tilapia and shrimp species that originate in the tropics and processors have clustered in these areas, also favoured by their proximity to container ports. According to the so called "*industrial clusters*" theory, concentration of many companies can gain more bargaining power than individual production facilities (Little 2004; Porter 1998; Porter 2000; Roth 2002).

Striped catfish has never developed past pilot production because it is too seasonally cool and arguably tilapia production is also constrained in its current areas of production by temperature. Exotic species such as tilapias and striped catfish are more likely to be affected by weather conditions as demonstrated by the huge loss of tilapia during particularly cold periods of 2008 (Cai & Liufu 2008). This is an example of a clear risk of using a non-indigenous species that may be more productive when conditions are optimal, but are more likely to suffer a total loss due to extreme weather–a good comparison is citrus in Florida and coffee in Brazil (Fortune & Kousky 1983; Marengo *et al.* 2002; Miller & Downton 1993; Rogers & Rohli 1991).

The view that developing countries always produce higher-value products, based on more intensive and resource-demanding processes for export markets, and much simpler to produce and lower value products for domestic markets has been challenged by the current analysis. While the export of relatively low market value tilapias has increased, shrimp has shifted from being an export commodity to domestic markets and freshwater prawns, with fetch high market value locally, have not entered export value chains. Market demand seems to be the biggest driver for aquaculture expansion, both locally and for export. A continued expansion of tilapia has been mainly driven by overseas demand, the shrimp expansion being driven by both domestic and export market, and more recently mainly by booming domestic demand, while the expansion of macrobrachium was domestic demand driven.

Compared with export markets, the domestic markets have lower food-safety standards (WTO 1998), and little, if any, considerations of sustainability. The domestic market is much less regulated, but easier for producers and dealer to sell products, and less affected by foreign economic and trade conflicts. However, companied by people more aware of food safety and environment issues, the requirement for market entrance will inevitably increase in the future.

Globalization driven by international trade and increasing domestic market demand have reinforced developments towards intensification and diversification of aquaculture practice. However, with greater geographical concentration and intensification of production of tilapias has come increased dependence on export markets, in contrast to the more scattered and diversified practices that characterise shrimp and fresh water prawns, especially for freshwater prawns, that are more domestically orientated. The flourishing domestic economy seems to be critical to aquaculture development and in China and to seafood exports. For example, after the ban on import of Chinese shrimp in 2004, domestic prices for shrimp still increased in the huge domestic market (Zhou 2010), in contrast with huge losses caused by EU ban to Bangladesh shrimp industry in 1997 (Cato & Lima Dos Santos 1998). A gradual reduction of farmed shrimp exports, and resultant exposure to less stable overseas markets promises a less vulnerable, more sustainable industry.

However, tilapia becoming more dependent on export markets, increases exposure to such risks that need to be reduced through more rigorous food safety control, and/or compliance with the international standards or certification schemes. At present, besides the mandatory export-oriented CIQ registration system for all export farmed seafood (China Entry-Exit Inspection and Quarantine Bureau 2004), a large number of facilities in China have achieved certification to various international sanitary standards such as the HACCP principles incorporated into ISO 22000 and extensively used, for example, in US Food and Drug Administration (FDA) inspections, GMP standards and the British Retail Consortium (BRC) Global Standard for Food Safety, as well as Chain of Custody certification under the Marine Stewardship Council (MSC) scheme (Hanson *et al.* 2010). The farming sector has also become involved in global certification schemes. A steady increase in the numbers of tilapia farms (27 tilapia certified by the Aquaculture Certification Council (ACC) in 2010 and 38 in 2014 (ACC 2014; Hanson *et al.* 2010); accounted for 80% of global ACC certified tilapia farms. In contrast only 13 certified shrimp farms had ACC certification, accounting for 14% of all certified shrimp farms (ACC 2014). The new established ASC certification also started work in China, but no farms have yet been certified (ASC 2014). However, compared with the large number of aquaculture farms, the number of certified farms remains very low, and local aquaculture certification schemes have evolved locally to ensure pollution-free products, China Good Agricultural Practice (ChinaGAP), organic products, and green food (Lv *et al.* 2009; Lu 2009; Li & Sun 2011). It is reported that certified farmed seafood such as organic products and pollution-free products increased quickly recently, and certified seafood has a much higher market price than conventional products (Li & Sun 2011; Xie *et al.* 2013).

Besides certifications, other market differentiation strategies could also be used to promote domestic production of tilapia, such as has been demonstrated in Thailand in which red, cage-reared tilapia were marketed as Thai ‘ruby’ fish differentiated from the natural coloured

‘Black sapphire’ niloiticus fish that had been established in local markets for thirty years. The Charoen Pokphand (CP) company created a new strain of red tilapia (*Oreochromis sp*.) cage farming system in 1990s, and was granted the name “*Plah Taptim*” (ruby fish) by the King of Thailand, and became a successful premium product, occupying a niche market in recent years (Belton *et al.* 2006; Mariojouls *et al.* 2004). The production of red tilapia in cages has been estimated at 30,000 mt year^{-1}, about 10% or more of total Thai tilapia production (Hambrey *et al.* 2008). CP’s product and market differentiation strategies were major reasons for success, which mainly include the distinguished name, attractive pink coloured fish and focus on high-value markets such as restaurants (Belton *et al.* 2006; Bhujel 2011; Rosenthal 2010). CP also initiated contract farming with several small-scale farms in groups, by supplying a complete package of technology, inputs such as fingerlings and feed, and buying back the grow-out fish (Bhujel 2011; Edwards 2011b; Hambrey *et al.* 2008), which was a very good strategy to promote any new species like tilapia (Bhujel 2011). In promoting tilapia domestic consumption, a campaign similar to the CP success case in Thailand is needed.

5. Chapter 5: Tilapia and shrimp farming in China: farming system, farm scale, production area, market orientation and their sustainability implications

5.1. Introduction

Aquaculture is commonly defined by type and scale of intensity of farming systems such as production technology, particularly feed input and area-based yield levels, in terms of extensive, semi-intensive and intensive, similar in concept to equivalent terms in agriculture (Edwards & Demaine 1998; Muir 2005). Measures of intensity include stocking density, production by area, feeding regimes and input costs, while the most interesting feature is the degree of control within the production process (Asche *et al.* 2008). Extensive systems receive no intentional nutritional inputs, but depend on natural food within the culture unit, while semi-intensive systems also depend on natural food, enhanced over baseline levels by fertilisation and/or use of supplementary feed to complement natural food. Intensive systems in contrast are totally nutritionally dependent on external feeds added to the system input, including forage fish and formulated so-called 'complete diets' (Edwards & Demaine 1998; Edwards *et al.* 1988; Edwards 1993; Muir 2005). The distinction between semi-intensive and intensive systems has become less clear, there may be an overlap between them, as increasing amounts of supplementary feed are provided to growing fish in a semi-intensive pond, the proportion of nutrition derived from natural food declines markedly relative to that of added feed so that the system increasingly resembles an intensive one in the later stages of the culture cycle (Edwards 2010). Intensification level also relates to the practice of monoculture or polyculture, where monoculture is commonly used for the intensive culture of a single, high-value species fed with formulated feed, and polyculture is more typical of rural aquaculture as two or more species are able to exploit different feeding niches of extensive and semi-intensive systems in which natural food predominates (Edwards & Demaine 1998). Shrimp farming systems can be broadly classified into three types: extensive, semi-intensive and intensive based on economic and technological differences (Shang *et al.* 1998). Tilapia farming ranges from a rural subsistence (extensive, low input practices, non-commercial and for household consumption) to a large-scale (capital intensive, commercial purpose and market driven) level, depending on the intensity of management employed (Gupta *et al.* 2004).

Government and development agencies and researchers frequently define farm scale based on indicators of physical size (land or water area, numbers of ponds etc.). This is consistent with their intuitive appeal as indicators of production output and ready availability of appropriate metrics. However, they are of limited value for comparison of different farming systems or levels of production intensity and offer a mono-dimensional interpretation of scale by excluding economic and social criteria. Terms related to farm scales, such as small-scale aquaculture farms or smallholders, are widely used, but the definition is often lacking or obscure, or defined imprecisely. The criteria for small-scale farms, for example, varies from FAO definition of subsistence farmers and small commercial farms (FAO 1998) to the European Commission definition of small and micro-businesses (Taylor 2001). Farm scales were linked to farming systems, resources input and intensification level, and especially rural aquaculture was defined as small-scale farming households or communities (Edwards & Demaine 1998). FAO (1998) defined farm scales according to level of production, complexity of farming systems with or without special ponds for broodstock, fry and fingerlings and storage, as well as the main ponds for producing food fish. Subsistence fish farms only have one or two ponds, mainly use for fattening or breeding/nursery alternatively with fattening, small-scale commercial farms usually have more ponds for spawning and nursery, and large-scale commercial farms may have the most complete range of fish-rearing facilities, including brood ponds and nursery ponds (FAO 1998). The World Bank (2008) defined smallholders as operating a farm of two ha or less in much of the developing world. The boundaries differentiating farm scales are not clear, nor the dynamic that characterises modern systems (Edwards 2010).

Small-scale farms support two billion people in the world and are more efficient in terms of output per acre, job creation, a source of local food security, and income generation (Tain & Diana 2007; Wegner & Zwart 2011). Asian aquaculture has been described as a mainly small-scale, family-owned, managed, and operated farming activity (De Silva & Davy 2009). However, such claims ignored the critical role of the private agribusiness sector and companies such as Charoen Pokphand (CP) in Thailand and elsewhere, and the roles of cold storage, processors, feed millers and pharmaceutical companies have been critical to the development of the sector (Little 2010).

Small-scale aquaculture farms often have been referred to as '*rural aquaculture*' or *'resource-poor households*' (Demaine 2009). Most small-scale aquaculture farms are in rural areas of developing countries, and have provided food as well as income to the rural poor (Bhujel 2012). The shrimp aquaculture sector has been dominated by small-scale farmers practicing extensive aquaculture (Bondad-Reantaso *et al.* 2012). In India, small-scale farmers (<2 ha) are responsible for 90% of the marine shrimp production (New 2003), and 80% of the shrimp farmers were small and of marginal scale (Srinath *et al.* 2000). In Thailand, shrimp farming is also numerically dominated by small-scale farms less than 1.5 ha (Kongkeo & Davy 2010) but are not small-scale in terms of any continued use of traditional culture techniques–they are supported by modern hatchery technology diets and water, and their high yields are totally supported by formulated and fossil-fuel powered aerations (Nietes-Satapornvanit 2014). Such conventional definitions no longer seem to fit with reality, Belton *et al.* (2012) proposed an alternative typology based on relationship to production around the categories of quasi-peasant, quasi-capitalist and capitalist forms of aquaculture and concluded the quasi-capitalist forms of aquaculture may possess greater potential to reduce poverty and enhance food security than the quasi-peasant modes of production, because (quasi) capitalist aquaculture was connected to longer and more complex value chains and wider networks of exchange.

According to an OECD report (2006), agriculture farms can be classified as large-scale commercial agricultural households and enterprises, traditional agricultural households and enterprises, not internationally competitive; subsistence agricultural households and micro-enterprises; landless rural households and micro-enterprises; and chronically poor rural households, many no longer economically active (OECD 2006). The OECD (2006) typology does not just consider farm scale, but also the governance, economic and trade power and social relationships. Farm scale is also related to farm ownership, farm management and farm labour. A trading name of a farming enterprise is a sign of scale and commercialization level, for example, having a trading name is necessary to get third party certification. Large-scale farms are more likely to be owned by large-scale vertically integrated companies, who also own processing, marketing, and export logistics, and for which ownership, management, and labour are separated functions (Deininger & Byerlee 2012).

The global aquaculture industry and farmed seafood exports are developing towards horizontal and vertical integration, with fewer large-scale companies controlling more market share-trends already demonstrated for salmon, striped catfish and tilapia (Asche *et al.* 2007; Gravningen 2007; Kvaløy & Tveterås 2008). Vertical integration occurs when an enterprise owns or controls more than one sector of the value chain, such as integration of producing, processing, transporting and distribution; whereas horizontal integration means an enterprise owns or controls multiple business in the same sector of the value chain, i.e. different 'branches' (Abila 2003). Driven by capital intensive, more large vertically integrated companies emerged in the salmon industry with direct ownership of production activities including hatcheries, fish processing and exporting (Kvaløy & Tveterås 2008). Growing horizontal and vertical integration in the agribusiness sector, has been mainly driven by gains from economies of scale and globalization of the food chain, multinational agro-enterprises increasingly dominate the agribusiness sector along the value chain (World Bank 2008). Key objectives of vertical cooperation in the market chain include: increasing profits through greater market share, improved product quality and product branding (Hanson *et al.* 2010). These trends in agribusiness consolidation, on-going on for years in industrial countries, are now becoming common in developing countries as well (World Bank 2008) but often with external drivers from importing countries such as concerns over food safety practices of smaller enterprises.

The status of China's aquaculture dominated by small-scale, family managed farms (Bean & Wu 2006; Xie & Yu 2007) focuses the challenges to improve food safety. The China Entry-Exit Inspection and Quarantine (CIQ) registration system was established in 2004 to ensure traceability from aquaculture farm or fishing vessel to final product of export aquatic products (China Entry-Exit Inspection and Quarantine Bureau 2004). The minimal aquaculture farm area that can request CIQ registration is 3.3 ha for enterprises with earthen ponds and 0.66 ha for concrete pond systems, which practically excludes most small-scale farms from the export value chain. At the same time, there is no similar functioning traceability system for aquatic products in domestic market.

Chinese land policy went through dramatic changes since the establishment of PRC in 1949 (Ding 2003). All farm land was collectively owned by either government or local village and no private land right existed before 1978. Along with the opening up of policy and economic reform, land policy also changed to more land rights being allocated to farmers in the form of a household contract responsibility system (Krusekopf 2002). Now most land can be divided into two types: private plots managed by single famer households and collectively controlled land which mainly managed either by local village committee or government (Li *et al.* 1998) that can be leased out in larger parcels of land. Recently, as part of government's land reform in order to raise agriculture productivity, land-use rights and land-rental markets have been enhanced (Huang *et al.* 2012).

Per capita productivity growth was the key to economic growth; however, it was largely ignored by policy makers and researchers (Collier & Dercon 2009). The Chinese government became more focused on increasing productivity and efficiency, rather than simply production in recent years (Bean & Wu 2005). Higher productivity can increase production per unit input, reduce working time, and eventually contribute to the welfare of society as a whole. Productivity growth leads to lower production costs and thus higher profit, which is the key to understanding why aquaculture production will continue to increase (Asche *et al.* 2008). *Per capita* productivity and employment impacts are important indicators of aquaculture's contribution to poverty reduction in developing countries (Ahmed & Lorica 2002). Aquaculture productivity differences evident in different countries largely reflect the variable availability of technology and energy, as high productivity intensive aquaculture requires both of them and these are often not readily or reliably available in low-income food-deficit countries (Frid & Paramor 2012). Aquaculture farms, whatever scale they are, need to be productive in order to be socially and economically sustainable (Edwards 2010).

Increases in on-farm productivity are crucial to bringing about sustainable, long-term reductions in poverty and hunger (Belton & Murshed-e-jahan 2013). Globalization and competition require farmers need to be competitive in global scale, the production of specific countries, regions or species may be reduced if they are not competitive in productivity and efficiency (Asche *et al.* 2008).

The production and processing of tilapias and shrimps in China are geographically concentrated in the south, especially in Guangdong province for both shrimp and tilapia and Hainan province for tilapia. Aquaculture development is inherently related to spatial distribution because of the differences among biophysical characteristics (e.g. water quality and quantity, soil type and climate) and socioeconomic characteristics (e.g. administrative regulations, competing resource uses, market, infrastructure, and availability of technical expertise) from location to location (Nath *et al.* 2000). Significant geographic differences can be found between two major tilapia producing and exporting areas Hainan and Guangdong, the most obvious being that is Hainan is an isolated island. Due to differences in latitude, average annual ambient temperatures in Hainan (24.6℃) are higher than that in Guangdong (21.8℃) in 2013, annual precipitation in Hainan (2,158 mm) also higher than in Guangdong (1,848 mm) (Guangdong Meteorologic Service 2014; Hainan Meteorologic Service 2014).

Aquaculture development and its sustainability need to be measured (Nobre *et al.* 2010), by indicators such as FCR and FIFO or broader indicator-based approaches such as LCA (Costa-Pierce *et al.* 2011; van der Werf & Petit 2002). The farm level survey became a common approach to collect data for aquaculture development and sustainability evaluation in recent years, include farming practice status, social economic aspect of farming and environment impacts (Phan *et al.*

2009; Philcox *et al.* 2010; Phong *et al.* 2007; Schwantes *et al.* 2009; Taylor *et al.* 2008; Whitmarsh & Palmieri 2009).

In order to balance the environmental and human objectives and make rational choices concerning sustainable development, the AMOEBA approach based on either quantitative or qualitative indicators was developed for sustainable development evaluation (Ten Brink 1991; Ten Brink *et al.* 1991). AMOEBA is the Dutch acronym for 'a general method of ecosystem description and assessment', which was used to compare the present ecological situation and the reference condition for the Dutch marine bio-diversity using selected environmental quality indicators (Ten Brink *et al.* 1991). AMOEBA diagrams enable a simple yet comprehensive, visualised performance comparison of two or more systems in qualitative or quantitative terms, to what extent the objective has been met for each indicator (López-Ridaura *et al.* 2002; Singh *et al.* 2007). AMOEBA was also used to evaluate broader sustainability issues by including social, economic and natural capital indicators, the asymmetry of the AMOEBA indicates the extent to which each farming system lacks sustainability or in which aspects each capital is weak (Koohafkan *et al.* 2012). AMOEBA has been identified as one important and holistic evaluation tool for gauging and communicating sustainability (Bell & Morse 2008).

Although China is a global leader in tilapia and shrimp farming and export, the culture practices remain largely unknown to the world. A systematic review (Chapter 4) demonstrated the major shrimp and tilapia farming systems include high-level pond shrimp system, low-level pond shrimp monoculture and polyculture systems, tilapia polyculture systems, tilapia livestock/poultry integrated systems, and reservoir tilapia farming system in the main producing area Guangdong and Hainan province. Besides farming systems, farming practice also related to farm scales, CIQ registration and export/domestic market orientation and farm geographic location.

This chapter aimed to improve understanding of shrimp and tilapia farming practices and their relationship with social and economic factors such as farm scales, farm location and export orientated CIQ registration through a large-scale baseline survey conducted in 2009-2010. After completion of the baseline survey, it is reported that shrimp and tilapia farming were facing constraints such as disease for shrimp and low farm gate price and disease for tilapia in China (Cui 2011; Liu 2011b). A further follow-up survey was therefore conducted at the farm level two years after the baseline survey in December 2012.

This chapter tried to answer the following research questions:

a) What are useful farm scale indicators for different farming systems and farming species? How did these indicators perform and relate to CIQ registrations and farm geographic location?
b) How did the intensification level relate to differences between different farming systems, farming scales, CIQ registration and farm location?
c) What was the productivity and efficiency performance of different farming systems, farming scales, CIQ registration and farm location?
d) How did farming practices change overtime?

5.2. Methodology

This chapter contains two parts describing the baseline and follow-up surveys.

5.2.1. Questionnaire design and piloting

A structured systematic questionnaire (Appendix 2) was designed through a collaborative effort by all SEAT project partners, and then tested and refined in the field by local partner together with other partners (Murray *et al.* 2011). The survey period was designed to understand practices in the previous lunar year, according to Chinese farmers' habit.

5.2.2. Team membership and training

The survey team included 14 enumerators employed by the local SEAT partner, Shanghai Ocean University (see Appendix 1 for team details), who arrived at survey site one month before the survey commenced for preparation. A two week training workshop was conducted during this period, included orientation to the research, clarification and understanding of the questionnaire content, coding system development, translation, Google satellite images analysis, and randomized farm selection exercise. After the training workshop, piloting of the draft questionnaire was conducted, the results discussed and analysed, and then the questionnaire and coding system developed on the basis of an amended and finalized version.

5.2.3. Independent stratification variables

5.2.3.1. Survey area

Based on scoping studies in chapter 4, major producing areas were selected as the survey area, included Zhanjiang district for shrimp, Maoming district in Guangdong province and Wenchang county in Hainan Province for tilapia, as these areas are important for both production and export.

5.2.3.2. Species

This research has two primary research species, namely shrimp and tilapia, and all farms were classified as tilapia or shrimp farms. All shrimp-tilapia polyculture farms were classified according to the major study species in that area, e.g. all shrimp-tilapia polyculture farms in Zhanjiang were classified as shrimp farms.

5.2.3.3. Farm scale

In this research a set of farm scale indicators was used to classify farms into small, medium and large-scale (Table 5.1).

Table 5.1 *A-priori* farm-scale indicators

	Indicator	Small	Medium	Large
1	Business ownership	Household/ extended family	Household external owner	Corporate
2	Management	Household/ extended family	Household/ salaried manager	Salaried manager
3	Full-time waged labour	No	Yes	Yes
4	Registered trading name	None	Yes/ No	Yes
5	Vertical integration	No	No	No/ Yes
6	Horizontal integration	No	No/ Yes	Yes

5.2.3.4. Farming system

Farming systems differed according to species. Piloting indicated that shrimp and tilapia farming systems included high-level pond shrimp systems, low-level pond shrimp systems, tilapia polyculture systems, tilapia integrated systems, and tilapia reservoir systems (Table 5.2).

Table 5.2 Farming systems by species, containment system and intensity

Species/system	Containment	Farming intensity
Shrimp	Pond	Intensive monoculture or polyculture 'low-level' – earth pond
Shrimp	Pond	Intensive monoculture 'high-level' – concrete or plastic film lined pond
Tilapia	Pond	Intensive & carp polyculture
Tilapia	Pond	Intensive & carp polyculture & integrated livestock (pig /duck/chicken)
Tilapia	Reservoir	Intensive - reservoir

5.2.3.5. CIQ registration

CIQ registration was primarily established for export products and enterprises in the export value chain, but was also related to farm scale due to the minimum land area requirement. Both CIQ farms and non-CIQ farms were surveyed and analysed in this study to explore differences.

5.2.4. Sample design

Sampling of cases for interview followed a multi-stage, multi-phase sampling approach. Multistage refers to the progressive resolution from larger to smaller sample units. This study included three stages from province and district level to the county level, and then to farm cluster level. The sample frame at province, district and county levels was based on secondary production data. Maoming district and Zhanjiang District in Guangdong province and Wenchang county in Hainan province were selected as research areas[8]. Google Earth satellite images were used to identify potential farms and farm clusters. Satellite imagery in Google earth was analysed to get data on pond numbers, farm area and system types. This information was used to narrow the selection to manageable 'clusters', usually one or more adjoining villages (Table 5.3).

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8 Chinese administrative division system: from central government, to provincial level, district level, county level, township level and administrative village level government

Table 5.3 Sample frame sources by multi-stage phase

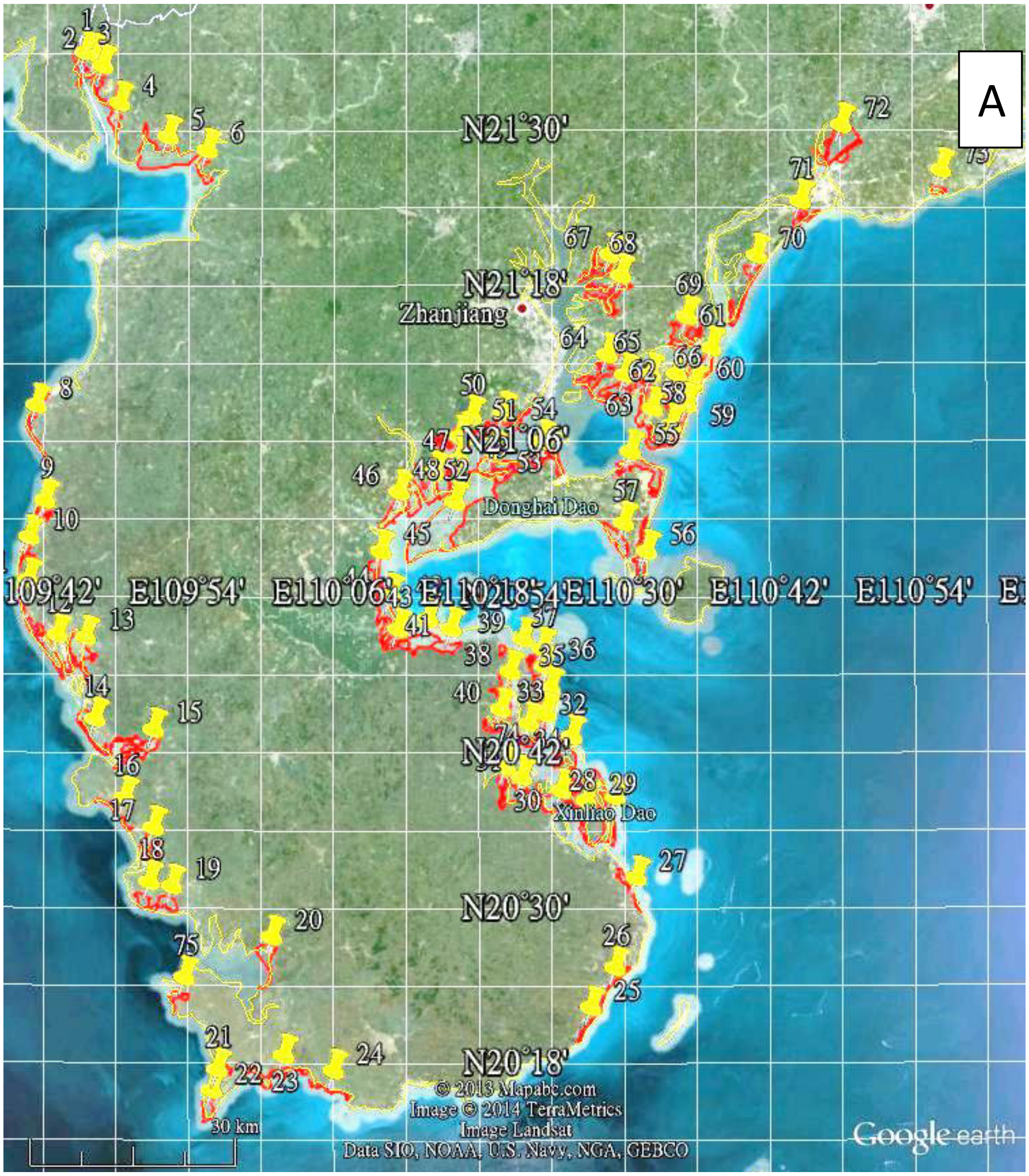
Country	Species	Multistage level	Sample frame	Aggregate level
China	Shrimp & tilapia	Province & District	Official statistics	Production
	Shrimp	County (Zhanjiang)	Official statistics	Production
	Shrimp & tilapia	Visual clusters	Google Earth	Visual clusters

Note: Terms in brackets indicate inconsistent resolution to some, but not all farms

5.2.4.1. Cluster sampling

Cluster sampling was usually practiced where the populations of interest were distributed over wide areas, making fully randomised sampling logistically impractical. Cluster sampling in this study involves sampling entire sub-populations in geographically discrete clusters, though as this was previously undertaken for representative producer areas here they were treated as tertiary sampling units.

Cluster size was determined by the number of ponds (50-300 in practice) deemed to provide sufficient scope for sampling of a pre-determined number of farmers per cluster. This included allowance for non-response i.e. due to availability or refusal etc. and logistical feasibility both in terms of inter-farm travel times. In practice clustering was based on visualisation of satellite images in the absence of suitable secondary data on individual farm location (Figure 5.1).


A
N21°30'
N21°18'
Zhanjiang
N21°06'
Donghai Dao
E109°54'
E110°06'
E110°30'
E110°42'
E110°54'
N20°42'
Xinliao Dao
N20°30'
N20°18'
30 km
© 2013 Mapabc.com
Image © 2014 TerraMetrics
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth

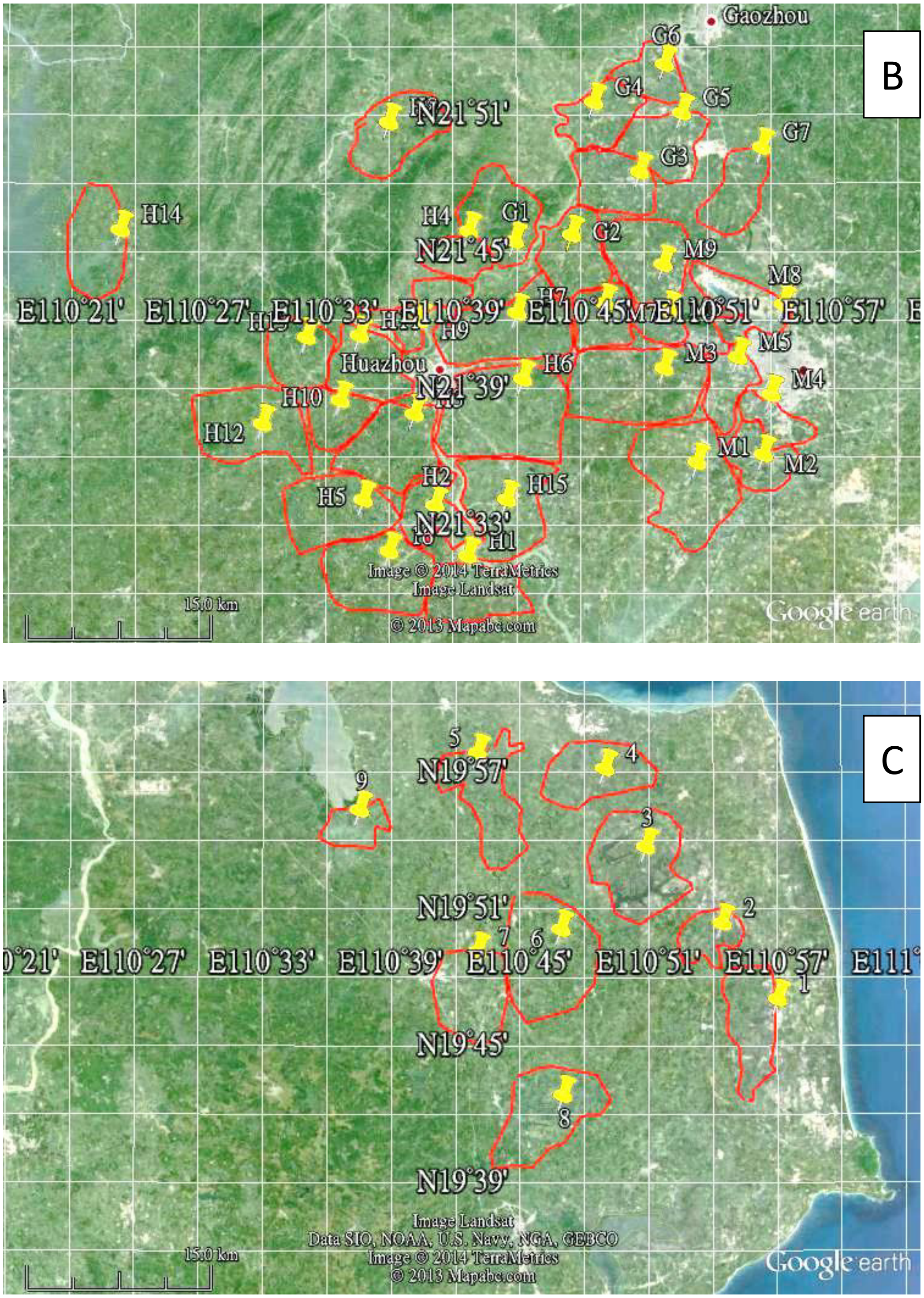


Figure 5.1 Farm clusters in Zhanjiang (A), Maoming (B) and Wenchang (C)

(Yellow placemarks with serial numbers are location of cluster and red polygons are area coverage of each cluster)

5.2.4.2. Sample size

A balanced sampling approach was adopted where the intention was to select roughly equal numbers of farms on each factorial combination of variables. This also facilitated a simple statistical rule of thumb of maintaining a minimum of 25-30 farms in each factorial cell of the two principal variables: species and scale.

Total sample size was determined according to resource availability. The target sample size was set at 400 farms consisting of 200 farms for of each of the two research species. The number of farms sampled per cluster ranged from 20-30 farms and therefore the number of clusters ranged from seven to ten per species.

5.2.4.3. Probability proportional to size (PPS) randomisation

Probability proportional to size (PPS) sampling approach was used (Skinner 2004). Randomised selection of (1) higher administrative regions and (2) clusters was achieved using the randomisation (RAND) function in Excel. Farms within clusters were then randomly selected during the survey by team members according to farmers' availability. To avoid selection bias (e.g. selection of the most accessible sites) each team members was assigned a small part of a cluster. The resulting selections were visualised in Google Earth using GPS (Global Position System) co-ordinates collected as part of the baseline survey.

5.2.4.4. Large-scale and CIQ farms

In order to get enough large-scale farms and CIQ registered farms, a snowballing approach was adopted (Goodman 1961). Key informants were mainly identified by local fisheries authorities.

5.2.5. Follow-up survey

The follow-up survey was based on baseline survey results as a reference, and aimed to find out major changes over time, and link these changes to underlying reasons for change where they were identified in shrimp and tilapia farming.

The follow-up survey sample frame was inherited from baseline survey. The questionnaire (Appendix 3) was modified from the tool developed in Vietnam and revised according to the Chinese context. Questionnaire piloting and enumerator training used the same procedure as for the baseline survey. The follow-up survey mainly relies on telephone survey. One phone call took approximately 10-20 minutes and a total 164 farms were surveyed. Based on telephone call survey results, around 20% (n = 30) farms that had made major changes were selected for field visit. Farm visit and interviews were conducted for triangulation and better understanding of any changes.

5.2.6. Data management and analysis

A fully normalised relational ACCESS (Microsoft 2010) database was developed for data management and analysis. This comprised 41 individual data tables together with associated tables for each pre-coded response system. Data used for analysis was retrieved from the ACCESS database using data-query tools.

Primary data were analysed using SPSS 21 statistic software (IBM 2013). Independent-samples Kruskal-Wallis test was used for significance test for continuous variables and Pearson Chi-Square was used to test for dichotomy variables. In order to get better accuracy, the following few steps were followed:

a) Data was extracted from Access database with the principle one farm one record (one line), which included Access query design, data checking and recoding.

b) Data checking in SPSS (Data explore-outliers), possible data triangulation with original questionnaires.

c) Data analysis, for nominal variable (categorical variable), calculation of frequencies and proportions; check significance using by Cross table (Chi-square).

d) For scale variable, calculate mean and standard deviation (sd), check significance by Nonparametric Tests: based on Independent Samples (Kruskal Wallis one way ANOVA)

5.2.7. Analytical structure

Before the analysis, basic farm properties were identified as species (tilapia/shrimp), scale (large/medium/small), CIQ registration (CIQ/non-CIQ), market (export/non/not sure), location (Guangdong/Hainan), pond/reservoir, poly/mono-culture, livestock/poultry integrated/non-integrated (tilapia) and high/low-level pond (shrimp). Such farm properties were too complex for cross analysis (Table 5.4)

Table 5.4 Cross analysis of different properties

	Species (Tilapia /Shrimp)	Scale(Large/Medium/Small)	CIQ(CIQ/non-CIQ)	Province(Guangdong/Hainan)	Pond/Reservoir	Poly/Mono culture	Integrated/Non-integrated (Tilapia)	High/Low-level pond (Shrimp)
Species(Tilapia/Shrimp)								
Scale(Large/Medium/Small)	√							
CIQ(CIQ/non-CIQ)	√	√						
Province(Guangdong/Hainan)	√	√	√					
Pond/Reservoir	√	√	√	√				
Poly/Mono culture	√	√	√	√	√			
Integrated/Non-integrated (Tilapia)	√	√	√	√	√	√		
High/Low-level pond (Shrimp)	√	√	√	√	√	√	√	

Note: √ is possible cross analysis

In order to simplify farm properties for analysis, all farm properties were grouped into two groups. Group 1 is farming practice related properties, include: species (tilapia/shrimp), pond/reservoir, poly/mono culture, integrated/non-integrated (tilapia), and high/low-level pond (shrimp). Group 2 is other social related properties (factors to be compared), include scale (large/medium/small), CIQ (CIQ/non-CIQ), and farm location (Guangdong/Hainan). And then group 1 farm properties were analysed and combined into six farming systems (Table 5.5)

Table 5.5 Six farming systems for analysis.

No	Groups	Abbreviation	Species	High/Low-level Pond/Reservoir	Poly/Mono Integrated/Non-integrated
1	high-level shrimp	S high	shrimp	high-level	
2	low poly shrimp	S low p		Low-level	poly
3	low mono shrimp	S low m			mono
4	pond integrated tilapia	T pond i	tilapia	pond	integrated
5	pond tilapia	T pond			non-integrated
6	reservoir tilapia	T re		reservoir	

Six farming systems and other social related properties (CIQ, farm scale and farm location) were cross compared with farm systems (Table 5.5). The analyses were compared separately for shrimp and tilapia farms.

Farm level associated indicators, such as primary farming species, farming systems, farm scales, farm locations, and CIQ registration were analysed in the first part of the results. Then farm scale related indicators, including total land area, total water area, total pond number, labour input, ownership, management and trading names, were analysed. Farm intensification level related indicators such as stocking density, farm yields, survival rate, eFCR[9], feed type, feed protein level, meal calculation, feeding methods, average pond size, water depth, crop duration and number of crops per year and in last five years, working hours and days were analysed to explore the intensification level of different farming systems farm scales, farm locations, and CIQ registration. Most of these indicators were based on values reported by farmers, except for eFCR included both reported eFCR (reported by farmers) and calculated eFCR (calculated based on total feed use and total harvest).

AMOEBA-type diagrams were made in qualitative terms, using indicators to compare productivity and efficiency of different farming species, farming systems, farm scales, farm location and CIQ registration. The highest value in one group data was set as the ideal value (reference value) and percentages of each value were then based on that reference value. All calculated values (percentages based on reference value) were presented in AMOEBA diagrams, where higher values (or closer to the outer ring, which represents 100% of reference value) represents higher

[9] eFCR: economic FCRs, defined as the amount of feed supplied to a farm divided by the volume of fish produced for market (Chiu et al. 2013).

productivity or efficiency. Indicators used in AMOEBA diagrams and their calculation methods were presented in Table 5.6. Labour input used in indicators here refers full-time labour, which include family labour, friend labour, and full-time salaried labour.

Table 5.6 Indicators and calculation methods used in AMOEBA diagrams

Indicators	Computation formula	Reference
Production per ha	= Total market harvest (kg) / total water area (ha)	
Value output per ha	= Total market harvest (kg) * farm gate price (CNY kg^{-1}) / total water area (ha)	
Production per labour	= Total market harvest (kg) / total labour number	
Value output per labour	= Total market harvest (kg) * farm gate price (CNY kg^{-1}) / total labour number	
Reported production per kg feed	= 1 / reported eFCR	
Calculated production per kg feed	= Total market harvest (kg) / total feed input (kg)	
Production per MJ energy	= Total market harvest (kg) / (total electricity input (kWh) * 3.6 (MJ per kWh) + total diesel (kg) * 42.65 (MJ kg^{-1}) + total gasoline (kg) * 43.07 (MJ kg^{-1}))	(AQSIQ & SAC 2008)
Value output per MJ energy	= Total market harvest (kg) * farm gate price (CNY kg^{-1}) / (total electricity (kWh) * 3.6MJ per (kWh) + total diesel (kg) * 42.65 (MJ kg^{-1}) + total gasoline (kg) * 43.07 (MJ kg^{-1}))	(AQSIQ & SAC 2008)

Follow-up survey results were presented as the last part of results, which included follow-up survey response, farm's profiles, farm changes status, major farm changes, future changes in plan, reasons for farms ceasing operation, farming practice and production changes, post-harvest changes, farm investment and farm income rank changes.

5.3. Results

5.3.1. Baseline survey result

5.3.1.1. Survey result

The survey lasted five months from 25th October 2010 to 10th March 2011. A total of 407 farms were surveyed, which included 200 shrimp farms in Zhanjiang district of Guangdong province, 135 tilapia farms in Maoming district of Guangdong province and 72 tilapia farms in the Wenchang city of Hainan province.

5.3.1.1.1. Farm scale indicators

Farms scales were analysed based on survey data for water area, farm labour, management, ownership, and farming system. Using the survey results, farm scale indicators were adjusted according to farming system and level of intensification and numbers balanced among different farming scales. The updated farm scale indicators were listed in Table 5.7.

Table 5.7 Farm scale indicators

Farming systems	indicators	1. Small	2. Medium	3. Large
Earth pond shrimp	Fulltime labour (salaried +family)	<=2	>=1 & <=7	>=7
	Water area (ha)	<=1	>1 & <=8	>=8
High-level pond shrimp	Fulltime labour (salaried +family)	<=2	>=1 & <7	>=7
	Water area (ha)	<=1	>1 & <6	>=2
Earth pond tilapia	Fulltime labour (salaried only)	<=2	<=3	>=3
	Water area (ha)	<3	>=3	>=14
Earth pond tilapia + livestock	Water area (ha)	<3	>=3	>=14
All	Management	By owner family	By owner family or By owner & salaried labour	By owner family or By owner & salaried labour
All	Ownership	Leased/Owned by family	Leased/Owned by family	Corporately owned

5.3.1.1.2. Farm and interviewee profiles

All farms were reclassified after the baseline survey using indicators such as farming systems, farm scales, district and CIQ registration. Farm profiles based on these indicators were presented in Figure 5.2.

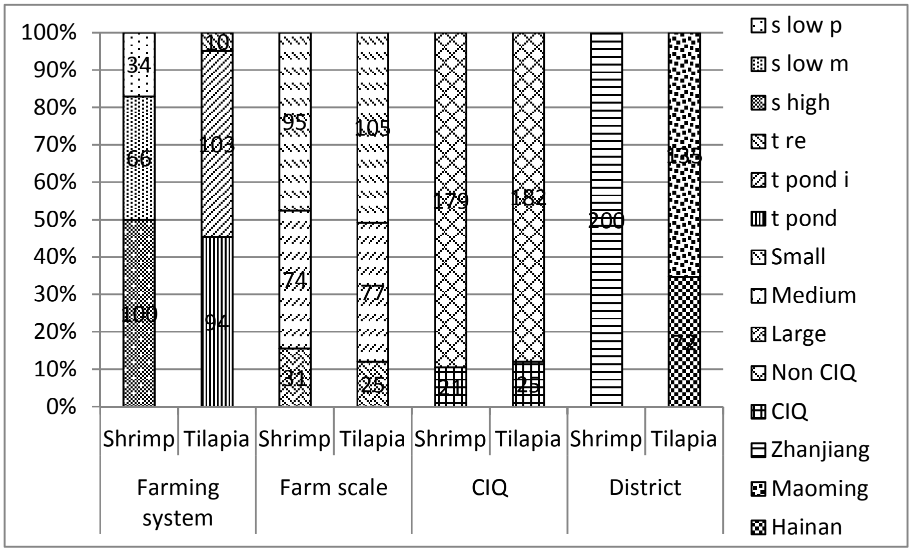


Figure 5.2 Shrimp and tilapia farm profiles by farming systems, farm scales, district and CIQ registration

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

Farm and interviewee profiles such as farm role, gender, age, years working in aquaculture, and education level were analysed and presented in Figure 5.3 for shrimp and tilapia farms.

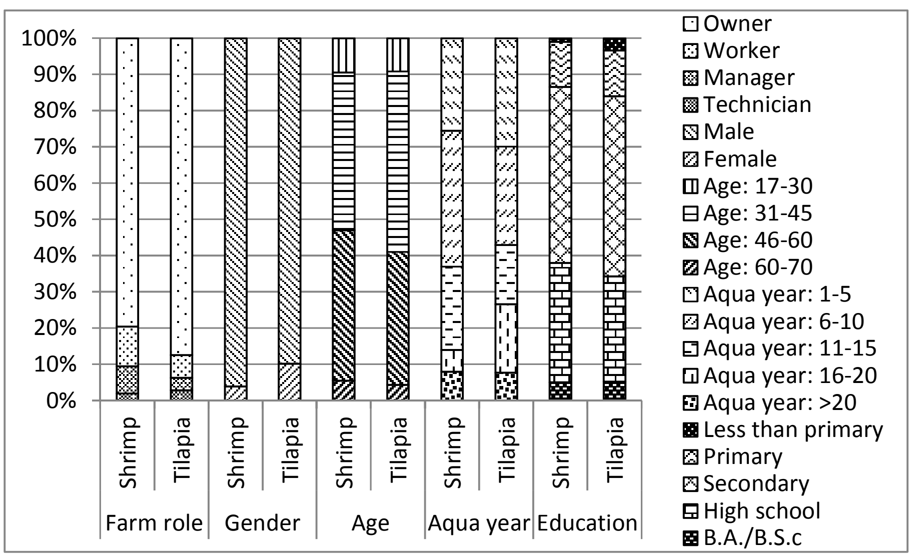


Figure 5.3 Farmers’ profiles by farm role, gender, age, aquaculture years, and education level

5.3.1.1.3. Relationships between farming systems and social-economic properties

Relationships between farming systems and other social properties including farm scale (Large/Medium/Small), CIQ registration (CIQ/non-CIQ), and farm location (Guangdong/Hainan) were analysed using Crossable (Chi-square) analysis in SPSS (Figure 5.4).

The results show farm scales were dependent on farming systems for both shrimp and tilapia ($P<0.01$). Large-scale shrimp farms tended to use high-level farming system, and small-scale farms tended to be low-level shrimp monoculture system. Most reservoir tilapia farms were large-scale, and small-scale farms tended to be integrated farming systems.

Although a higher proportion of shrimp farms with CIQ registration used high-level pond system than non- CIQ shrimp farms, the difference was not significant ($P>0.05$). Tilapia farming systems was dependent on CIQ registration ($P<0.01$), a higher proportion of reservoir tilapia farms were CIQ registered than tilapia pond farms and a very low proportion of integrated tilapia farms was CIQ registered.

All shrimp farms were in Zhanjiang district, while tilapia farming system was dependent on farm location ($P<0.01$). A much higher proportion non-integrated tilapia farms and medium-scale farms was founded in Hainan than that in Maoming ($p<0.01$).

CIQ registration was dependent on farming scale for both shrimp and tilapia ($P<0.01$). Large-scale shrimp and tilapia farms were more likely to have CIQ registration than medium and small-scale farms.

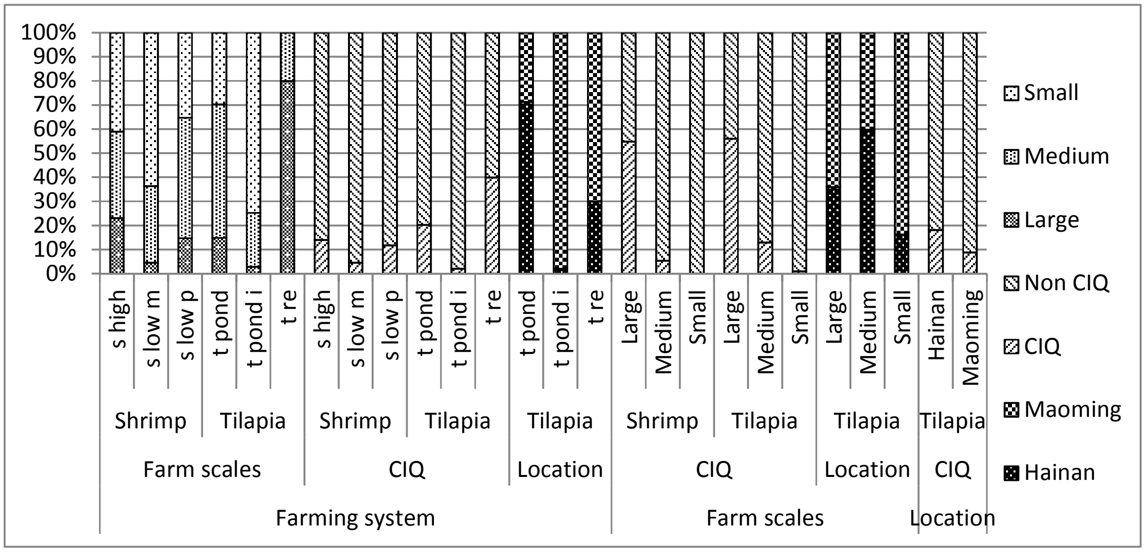


Figure 5.4 Farm profile and distribution among farming systems, farm scales, CIQ registration, and farm location

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.2. Farm scale profiles

5.3.1.2.1. Ownership of business

The type of shrimp and tilapia farm ownership was independent of farming system, but dependent on farm scale, CIQ registration and farm location (tilapia) ($P<0.01$). Forty five per cent shrimp farms were leased from the village, followed by 25% owned by family and 19.5% leased from private owners. Fewer large-scale shrimp farms were owned by the farmers' family, but more large-scale farms were corporate-owned or leased from the government or local village. CIQ shrimp farms were also mainly corporate- owned or leased from the village. Tilapia farms were mainly leased from the village (61.8%), owned by the family (20.8%) or leased from private owners (11.6%). More small-scale and non-CIQ farms are family-owned than medium and large-scale or CIQ farms (Figure 5.5).

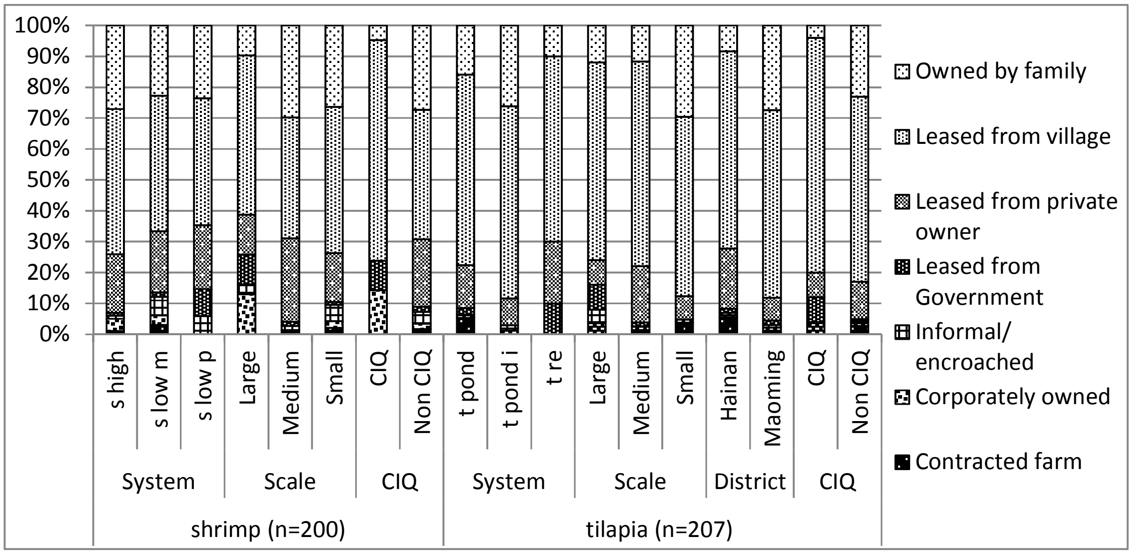


Figure 5.5 Ownership of business by species, farm scale and CIQ registration

(s high= shrimp high-level farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.2.2. Management

Farm management was dependent on farm scale, farm systems, and CIQ registration ($P<0.01$), but independent of location for tilapia ($P>0.05$). Large-scale and CIQ shrimp and tilapia farms were more likely to be managed by salaried labour and absentee owners. More low-level shrimp farms were managed by the owner's family, while reservoir tilapia farms tended to be managed by salaried employees (Figure 5.6).

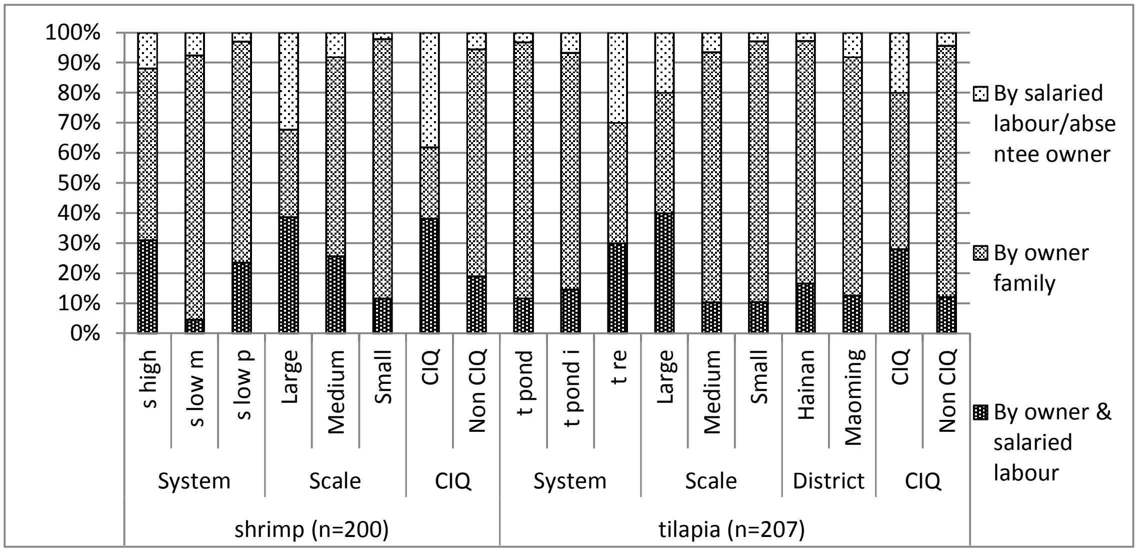


Figure 5.6 Farms management by species, farming systems, farm scales, farm location and CIQ registration

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.2.3. Trade names

Most farms didn't have trade names. Using a trade names was dependent on farm scale, CIQ registration and farming system for tilapia, but independent of farming systems for shrimp and farm location for tilapia (P<0.01). More large-scale farms and reservoir tilapia farms had a trade name. CIQ farms were required to have a trade name, as the name is part of the registration process (Figure 5.7).

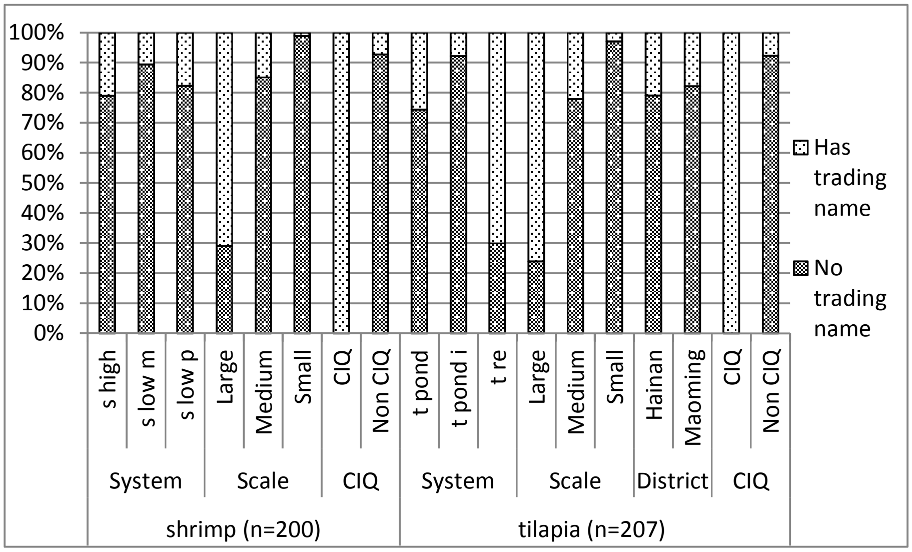


Figure 5.7 Farms with registered trade names, organised according to species, farm scale and CIQ registration

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.2.4. Total land area

Land area varied by farming systems and scales, CIQ registration and farm location. Significant differences were found for both shrimp and tilapia farms among different farming systems, farm scales, farm location and CIQ registration. CIQ farms were bigger than non-CIQ farms, and tilapia farms in Hainan were bigger than in Maoming. For farming systems, high-level shrimp farms were bigger than low-level shrimp farms, and reservoir tilapia farms were bigger than tilapia pond farms, and non-integrated pond tilapia farms were bigger than the integrated systems (Figure 5.8, Figure 5.9).

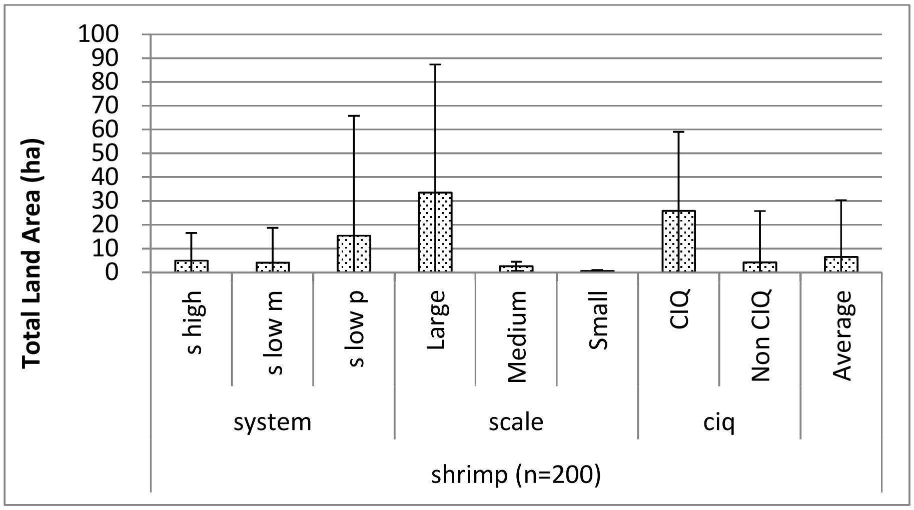


Figure 5.8 Total land area of shrimp farms by farming system, farm scale, CIQ registration, and farm location

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, and s low p = low-level shrimp polyculture farms) (unit: ha)

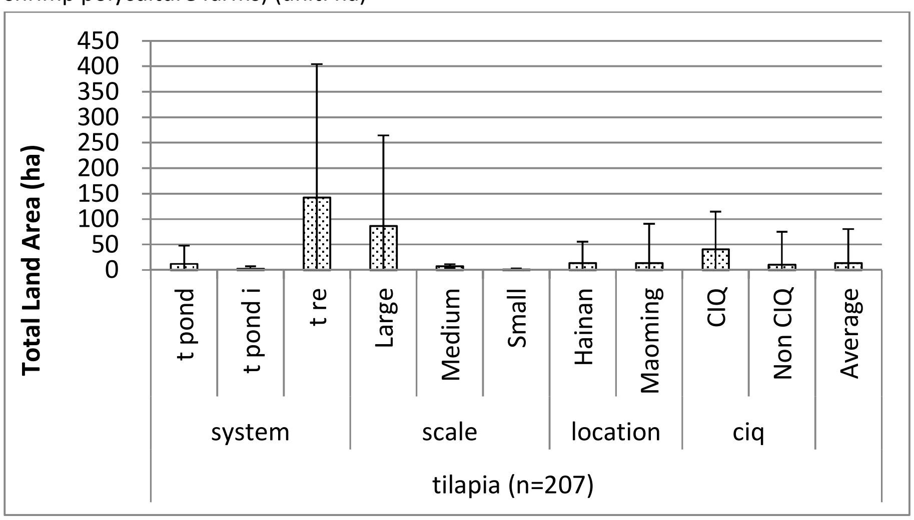


Figure 5.9 Total land area of tilapia farms by farming system, farm scale, CIQ registration, and farm location

(t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms) (unit: ha)

5.3.1.2.5. Total water area

The total water area also varies among different farming systems, farm scales, CIQ registration and farm location. Significant differences were found for both shrimp and tilapia farms among different farming systems, farm scales, farm location and CIQ registration. CIQ farms had more total water area than non-CIQ farms, and tilapia farms in Hainan had more water area than that in

Maoming. High-level shrimp farms and low-level polyculture farms had larger water areas than low-level shrimp monoculture farms, and reservoir tilapia farms more water area than tilapia pond farms, and non-integrated pond tilapia farms more than integrated systems (Figure 5.10, Figure 5.11).

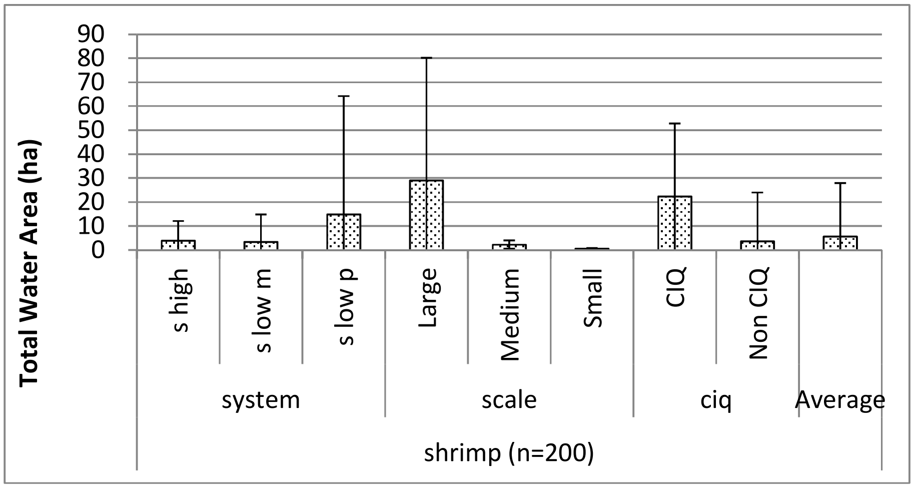


Figure 5.10 Total water area of shrimp farms by farming system, farm scale, CIQ registration, and farm location

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, and s low p = low-level shrimp polyculture farms) (unit: ha)

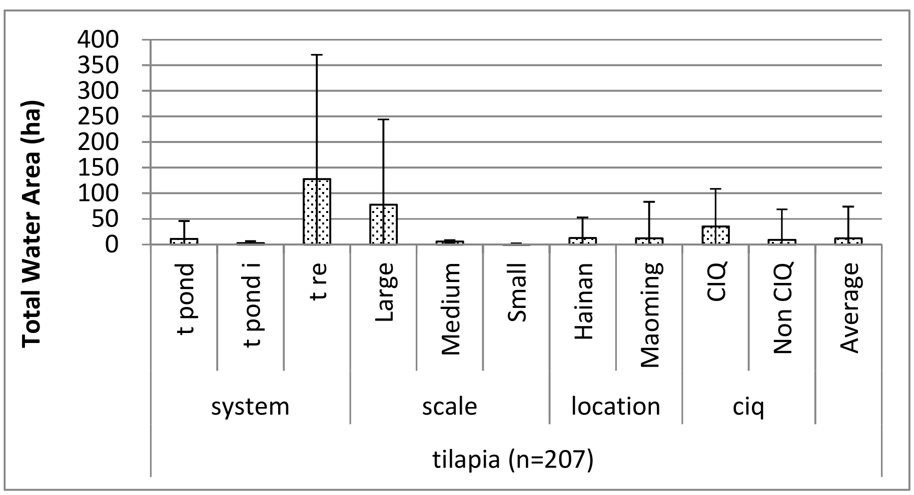


Figure 5.11 Total water area of tilapia farms by farming system, farm scale, CIQ registration, and farm location

(t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms) (unit: ha)

5.3.1.2.6. Total pond number

Total pond number also varied between different farming systems, farm scales, CIQ registration and farm location. The total pond number is a criterion for farm scale and there were significant difference between different farm scales. Besides farm scales, CIQ farms had more ponds than non-CIQ farms, and tilapia in Hainan had more ponds than that in Maoming. High-level shrimp farms had more ponds than low-level shrimp farms, and reservoir tilapia farms had more ponds than tilapia pond farms, and non-integrated pond tilapia farms had more ponds than the integrated systems (P<0.05) Figure 5.12).

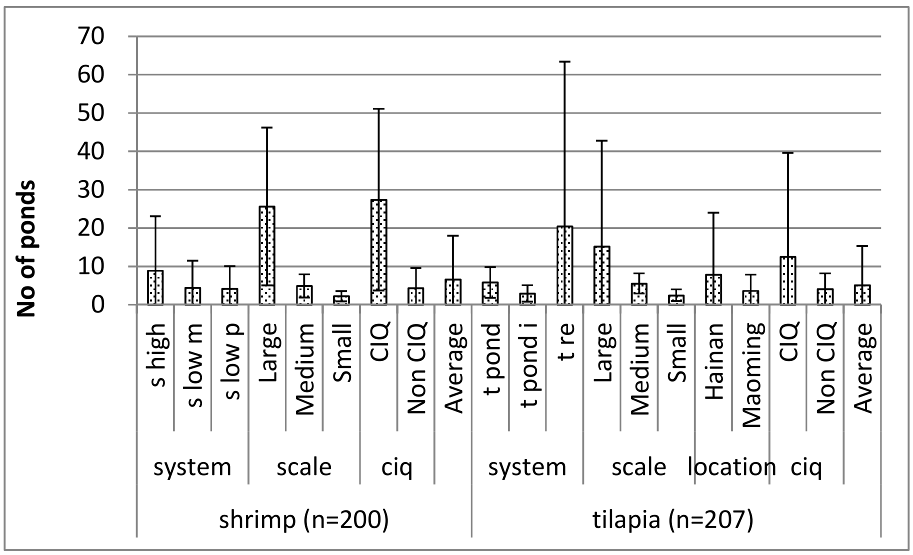


Figure 5.12 Total pond number by species, farming system, farm scale, CIQ registration, and farm location

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.3. Pond characteristics

5.3.1.3.1. Pond type

All farms had dedicated grow-out ponds, while 137 farms had dedicated nursery ponds, and eight farms had dedicated clean water storage ponds. Tilapia farms had more dedicated nursery ponds than shrimp farms (P<0.01), and shrimp farms were more likely to have clean water storage pond than tilapia farms (P<0.05). Only 6% (n = 12) shrimp farm had dedicated nursery ponds, compared with 59.9% tilapia farms that had dedicated nursery ponds. And 3.5% (n = 7) shrimp had dedicated clean water storage pond compared to only 0.5% (n = 1) of tilapia farms. High-level shrimp farms had more dedicated clean water storage ponds than low-level shrimp farms (P<0.01), and reservoir tilapia farms and tilapia non-integrated farms had more nursery ponds than integrated tilapia farms (P<0.01). Large-scale shrimp and tilapia farms and CIQ farms had more dedicated nursery and clean water storage ponds than non-CIQ farms (Figure 5.13).

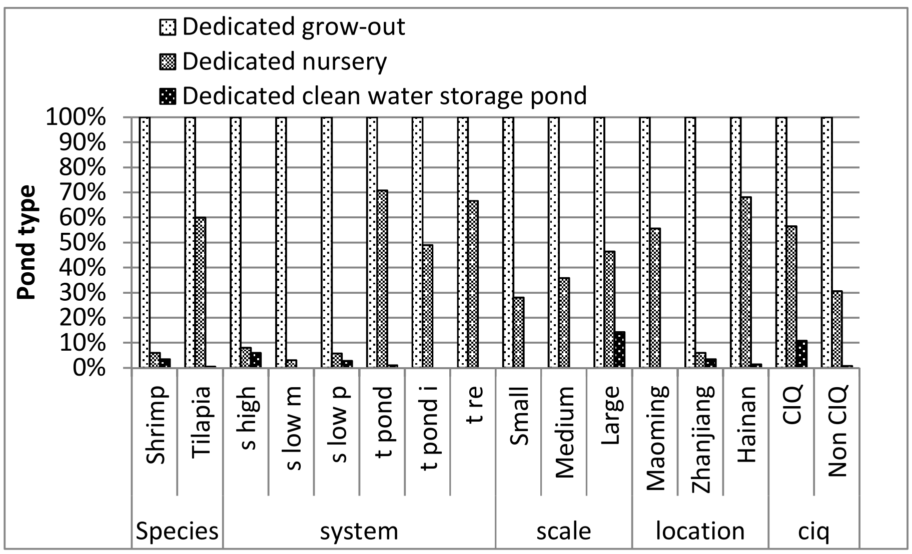


Figure 5.13 Pond type of tilapia and shrimp farms by farming systems, farm scales, farm location and CIQ registration status

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.3.2. Average pond size

Shrimp farms had smaller average pond sizes (0.47±0.39 ha, n=200) than tilapia farming (2.45±13.44 ha, n=206) (P<0.01).

High-level shrimp farms had smaller ponds than low-level shrimp monoculture farms and shrimp polyculture farms. Shrimp monoculture farms also had smaller ponds than shrimp polyculture farms (P<0.01). Small-scale farms had smaller ponds than both medium and large-scale farms, medium-scale farms smaller than large-scale (P<0.01). CIQ farms had bigger ponds than non-CIQ farms (P<0.01).

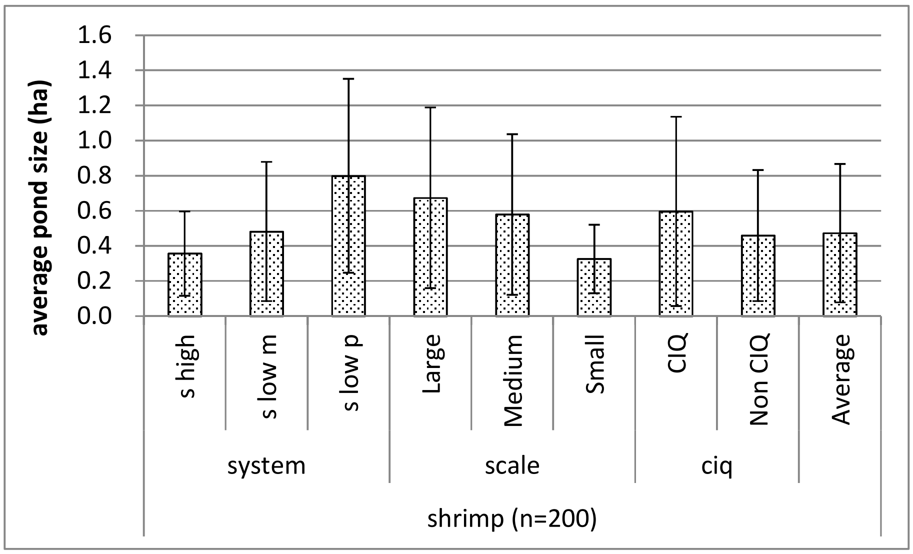


Figure 5.14 Average pond size in shrimp farms by farming systems, farm scales, and CIQ registration status

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, and s low p = low-level shrimp polyculture farms)

Pond sizes in reservoir tilapia farms, large-scale farms, tilapia farms in Maoming and CIQ farms were bigger than in pond tilapia farms, medium and small-scale farms, tilapia farms in Hainan and non-CIQ farms respectively (P<0.01). The main reason for such difference was the uneven distribution of reservoirs farms and large difference in the average size of reservoirs (42.39±55.43 ha, n=9) and excavated ponds (1.36±2.75 ha, n=198) (P<0.01).

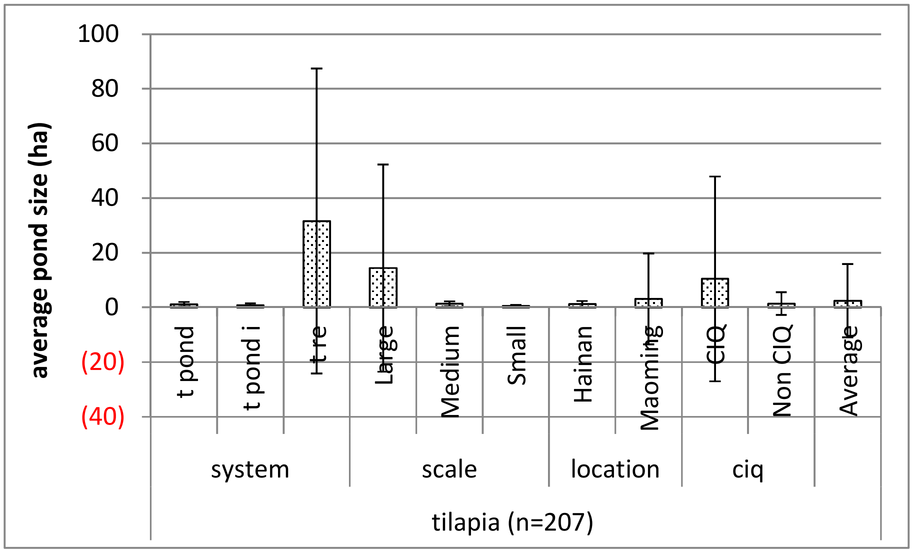


Figure 5.15 Average pond size in tilapia farms by farming systems, farm scales, farm location and CIQ registration status

(t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.3.3. Water depth of grow-out pond

Tilapia ponds were deeper than shrimp ponds in general (P<0.01). Grow-out ponds in high-level shrimp farms were deeper than low-level shrimp farms (P<0.01). No difference in pond depth was observed among farms of different scales and it was unaffected by CIQ registration.

Reservoirs (7.67±4.97 m, n=9) were more than twice the depth of excavated tilapia ponds (3.24 ±1.13m, n=198) (P<0.01). Reservoir tilapia farms, large-scale farms, tilapia farms in Maoming and CIQ farms were deeper than tilapia pond farms, medium and small-scale farms and, tilapia farms in Hainan and non-CIQ farms (P<0.05).

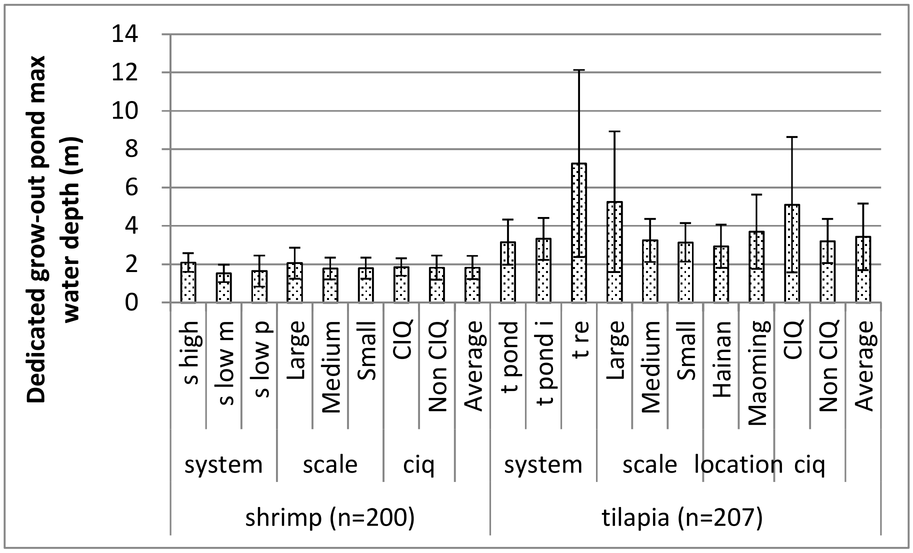


Figure 5.16 Max water depth of growth out pond of tilapia and shrimp farms by farming systems, farm scales, farm location and CIQ registration status

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.3.4. Lining material in grow-out ponds

Shrimp farming system definition was partly based on the pond lining materials used and the distinction between high and low-level shrimp ponds. Among high-level shrimp farms, 33% (n = 33) reported using concreted ponds, 65% (n = 65) used plastic liners, and 2% (n = 2) brick or stone to line ponds. Among low-level shrimp farms, one farm reported using earth pond with concrete dikes. Besides farming systems, no difference was found among different farm scales, CIQ registration, and farm locations (P>0.05).

Most tilapia farms didn't use pond liners and only 2.4% (n = 5) farms reported their grow-out ponds had concrete banks. There was no difference between farming systems, farm scales, CIQ registration, and farm locations.

5.3.1.4. Farm labour input

5.3.1.4.1. Total labour inputs

Farm labour includes family labour, friends and relatives and hired full-time labour. The total amount of labour varied by species, farming system, scale, location and CIQ registration status. High-level shrimp farms had more labour inputs than low-level monoculture farms (P<0.05), and large-scale shrimp farms had more than medium and small-scale shrimp farms (P<0.01), CIQ shrimp farms also had more labour input than non-CIQ shrimp farms (P<0.01). Reservoir tilapia farms had more labour input than tilapia pond farms, and large-scale tilapia farms had more than medium and small-scale farms, CIQ farms also had more than non-CIQ farms (P<0.05). No difference was found between Maoming and Hainan (P>0.05).

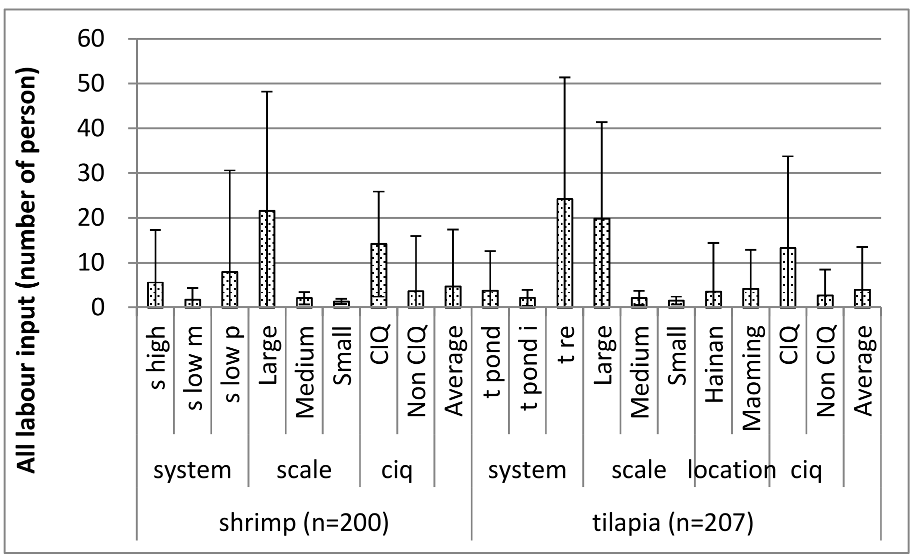


Figure 5.17 Total number of all labour input per farm by species, farming system, farm scale, CIQ registration, and farm location

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.4.2. Hired full-time labour

High-level shrimp farms had more hired labour than low-level monoculture farms (P<0.05), and large-scale farms more than medium and small-scale farms (P<0.01), CIQ farms also used more labour inputs than non-CIQ farms (P<0.01). Reservoir tilapia farms had more labour input than tilapia pond farms, and large-scale farms had more than medium and small-scale farms, CIQ farms also had more than non-CIQ farms (P<0.05). No difference was found between Maoming and Hainan (P>0.05).

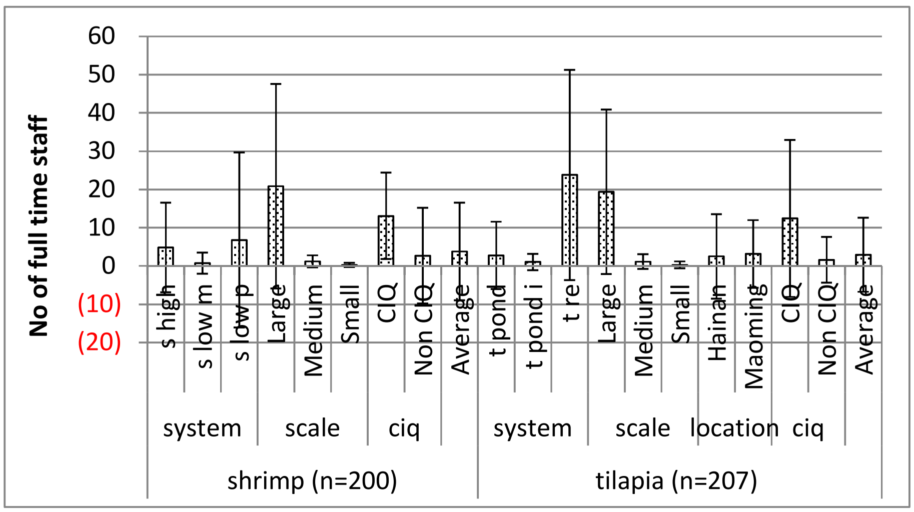


Figure 5.18 Total number hired labour-full-time workers by species, farming system, farm scale, CIQ registration, and farm location

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.4.3. Daily working hours

Shrimp farms required more labour than tilapia farms and the labour contributions were higher for both family & friend labour and full-time hired labour input than that of tilapia (P<0.01).

High-level shrimp farms had higher working hours for family & friend labour than low-level shrimp monoculture farms and polyculture farms (P<0.05). There were no differences in working hours of family & friends among shrimp farms of different scales and CIQ registration (P>0.05). No differences in working hours of full-time hired labour were found among different shrimp farming systems, scales and CIQ registration (P>0.05).

Reservoir tilapia farms had higher working hours of both family & friend labour and full-time hired labour than tilapia pond farms (P<0.05). Large-scale tilapia farms and CIQ farms had higher working hours (of family & friend)than medium and small-scale tilapia farms, and non-CIQ farms respectively (P<0.05). No difference was found between Hainan and Maoming (P>0.05).

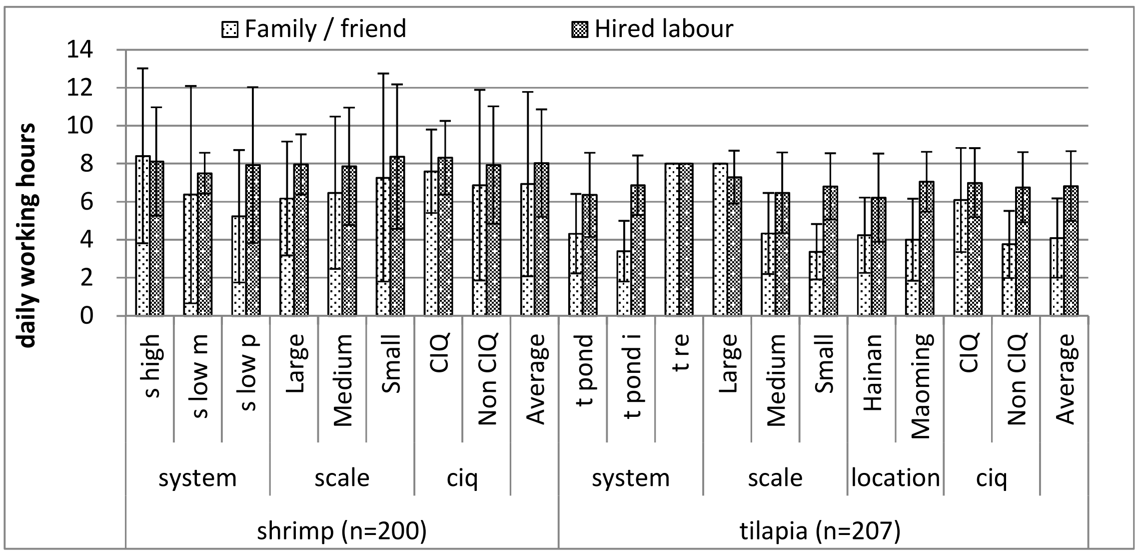


Figure 5.19 Daily working hours of family/friend labour and hired labour of tilapia and shrimp farms by farming systems, farm scales, farm location and CIQ registration status

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.4.4. Annual working days

As neither family labour nor friends labour are paid wages by the farmer, they were analysed together. Family & friends labour inputs through the year for shrimp farms is less than tilapia farms (P<0.01) but there was no difference for full-time hired labour (P>0.05).

High-level shrimp farms were supported with more labour from family & friends than low-level shrimp farms (P<0.01), but used less full-time hired labour than shrimp polyculture farms (P<0.05). CIQ shrimp farms also had higher labour inputs based on family & friends than non-CIQ shrimp farms (P<0.05).

No difference was found in tilapia farms in terms of family & friend labour and full-time hired labour annual working days among different farming systems, farm scales, location and CIQ registration (P>0.05).

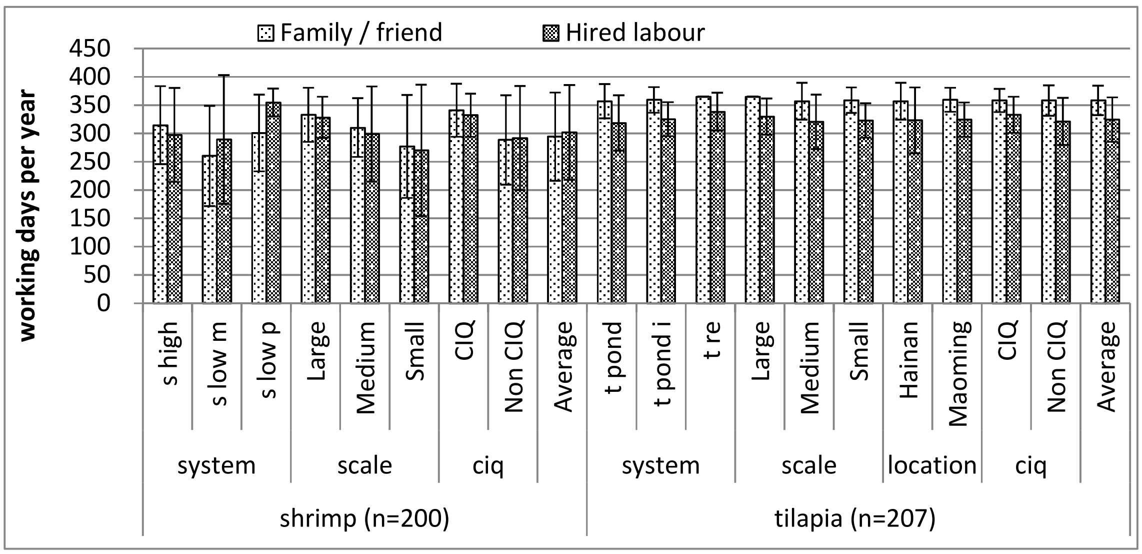


Figure 5.20 Annual working days of family/friend labour and hired labour of tilapia and shrimp farms by farming systems, farm scales, farm location and CIQ registration status

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.5. Feed input

5.3.1.5.1. Feed type

Commercial pelleted feed is widely used in tilapia and shrimp farming in China. Almost 100% (99.5%) of shrimp farms reported using commercial pellet. Only a single farm, a large-scale, shrimp low-level monoculture, CIQ registered farm reported using both commercial and on farm feeds. Most (93.2%; n=193) tilapia farms reported using commercial pelleted feeds, 5.8% (n = 12) reported using on-farm pelleted or wet feeds, and 1% (n = 2) reported using both commercial and on farm feeds. No difference was found among different farming systems and CIQ registration (P>0.05). But 20% (n = 5) of large-scale farms reported using on farm pelleted or wet feeds or both commercial and on farm feeds, higher than 7.8% (n = 6) of medium and 2.9% (n = 3) of small-scale farms. In Hainan, all farms reported using only commercial pelleted feeds, compared to Maoming where only 89.6% (n = 121) farm only use commercial pelleted feeds (P<0.05). Significant differences were found with respect to use of formulated diets by farming system (P<0.01), farm scale (P<0.05) and farm location (P<0.01) (Figure 5.21).

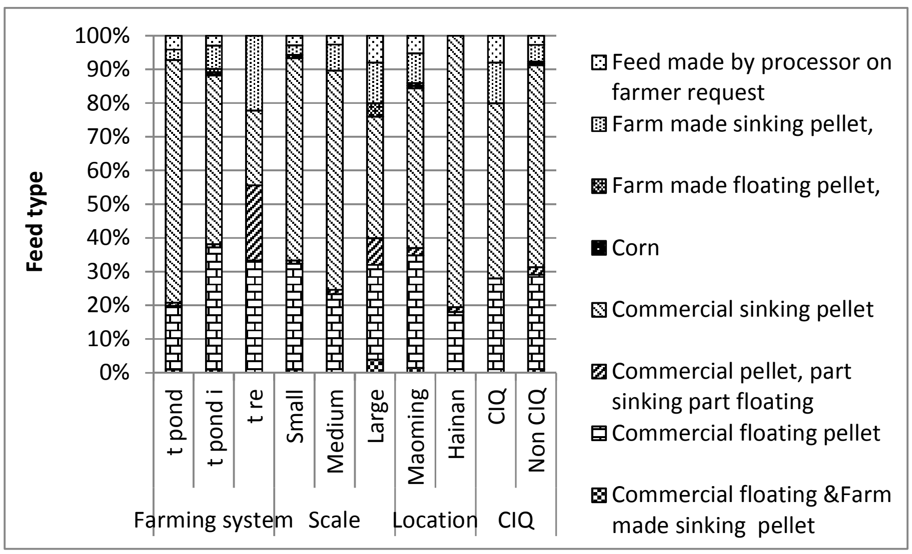


Figure 5.21 Feed type in tilapia farms of farming systems, farm scales, farm location and CIQ registration status

(t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.5.2. Feed protein level

No difference in mean feed protein level were found among shrimp farming systems, but large-scale shrimp farm and CIQ shrimp farm reported lower protein level feed than small-scale farms or non-CIQ farms (P<0.05). Reservoir tilapia farms tended to use higher protein level feed than tilapia pond farms, and tilapia farms in Maoming tended to use higher protein level feeds than Hainan-located farms, non-CIQ tilapia farms also reported higher protein level feeds than CIQ tilapia farms (Figure 5.22).

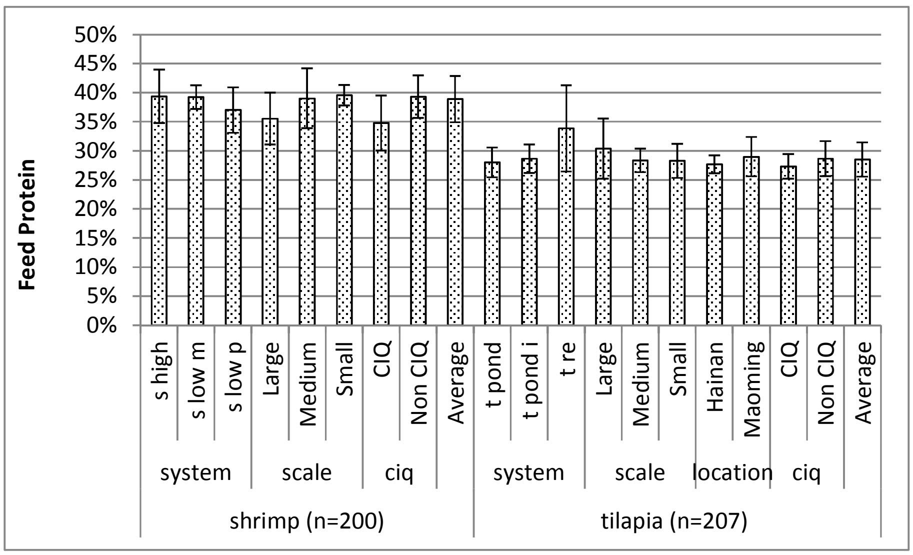


Figure 5.22 Feed protein level of tilapia and shrimp farms by farming systems, farm scales, farm location and CIQ registration status

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.5.3. Feeding

More than 80% (81.5%, n=163) shrimp farms reported using feed trays to present feed and calculate amounts given, followed by 11.5% (n = 23) feeding to appetite (*ad libitum*), 3% (n = 6) by estimation, 3% (n = 6) based on crude estimates of biomass, 0.5% (n = 1) by% body weight using sample weights & mortality recording, and 0.5% (n = 1) by cast-netting and biomass by volume calculation.

45.9% (n = 95) tilapia farms reported using crude estimates of biomass to calculate feeding rates followed by 31.4% (n = 65) feeding to appetite (*ad libitum*), 16.9% (n = 35) by estimation, 4.3% (n = 9) by % body weight using sample weights and mortality recording, 1% (n = 2) by weather and biomass, and 0.5% (n = 1) farm data not collected.

No difference was found among different shrimp and tilapia farming systems, farm scales, CIQ registration and farm location (P>0.05).

5.3.1.5.4. Feeding method

Ninety nine percent (n = 198) of shrimp farms reported only using hand/manual feeding by staff from dyke, boat or feeding site. Only two farms reported using both hands feeding and automatic feeding machine, both of them were shrimp polyculture farms.

Nearly 90% (89.4%, n=185) tilapia farms reported using automatic feeding machines, with only 9.6% (n = 20) using both hand and automatic feeing machine and 1% (n = 2) farm data not collected.

No difference was found among different shrimp and tilapia farming systems, farm scales, CIQ registration and farm location (P>0.05).

5.3.1.6. Farm intensification level

5.3.1.6.1. Mean crop grow-out days

Shrimp farming had much shorter grow-out duration (92.30±13.74 days n=200) than tilapia farming (214.75±76.91 days n=204) (P<0.01).

High-level shrimp farms, small-scale farms and non-CIQ farms had shorter grow-out duration than low-level shrimp polyculture farms, large-scale farms and CIQ farms respectively (P<0.05). Tilapia farms in Maoming had shorter grow-out period than that in Hainan (p<0.01). No difference was found among different tilapia farming systems, farming scales and CIQ registration (p>0.05).

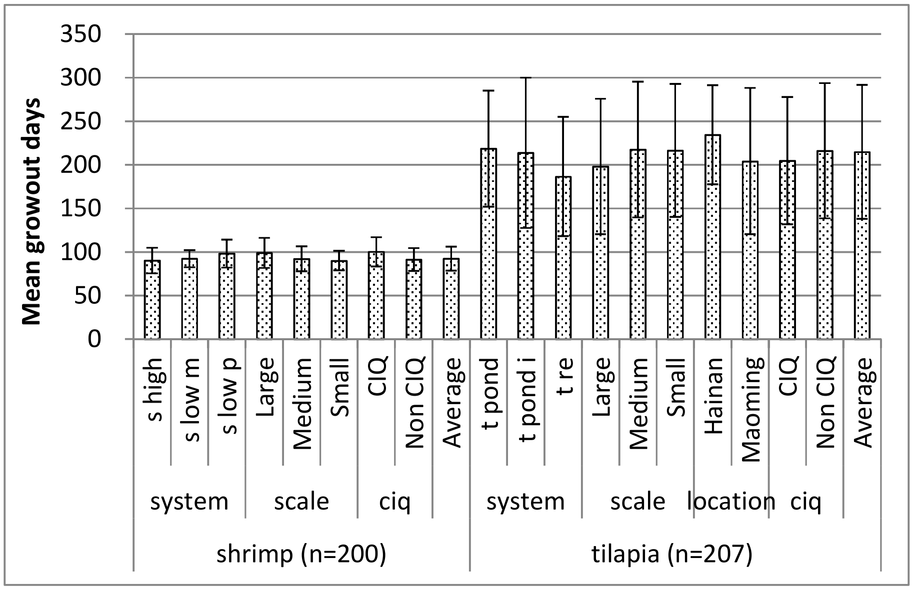


Figure 5.23 Cycle duration of tilapia and shrimp farming by farming systems, farm scales, farm location and CIQ registration status

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.6.2. Number of farming cycles per year

Shrimp farming had a greater number of farming cycles per year (2.44±0.62, n=196) than tilapia farming (1.65±0.58, n=206) (p<0.01).

High-level shrimp farms had more culture cycles per year than low-level shrimp polyculture farms (P<0.05). Tilapia farms in Maoming had more production cycles per year than that in Hainan (P<0.01). No difference was found among different shrimp farm scales and CIQ registration, and tilapia farming systems, farming scales and CIQ registration (P>0.05).

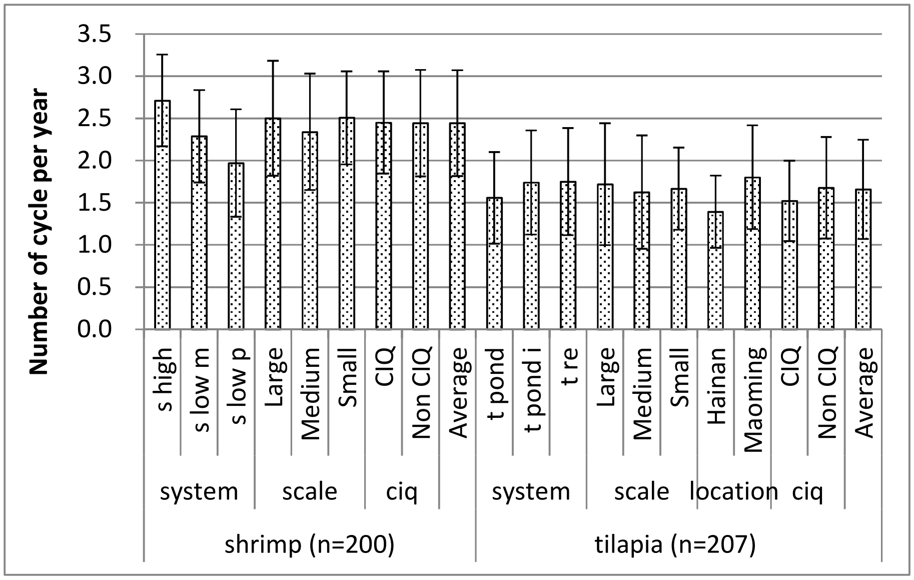


Figure 5.24 Number of cycles per year of tilapia and shrimp farming by farming systems, farm scales, farm location and CIQ registration status

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.6.3. Stocking density

High-level shrimp farms had much higher stocking densities (by factor of 2.5) than low-level shrimp farms (P<0.01), while small-scale farms also had a higher stocking density than medium and large-scale farms (P<0.05). No difference was found between farms of different CIQ registration status (P>0.05) (Figure 5.25).

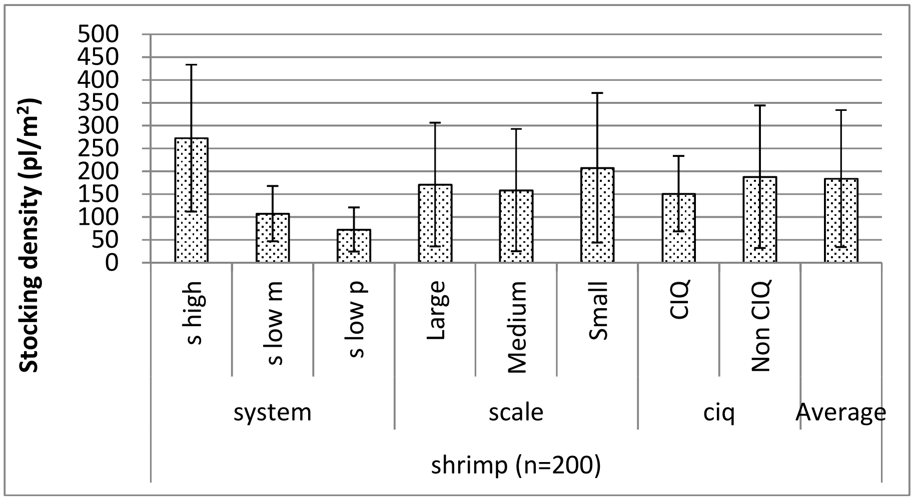


Figure 5.25 Shrimp stocking density of by farming systems, farm scales, and CIQ registration status

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, and s low p = low-level shrimp polyculture farms)

Reservoir tilapia farms had lower stocking densities than pond farms (P<0.05), and tilapia farms in Hainan and medium-scale farms had higher stocking densities than farms in Maoming and small and large-scale farms (P<0.01). No difference was found between farms with different CIQ registration status (P>0.05) (Figure 5.26).

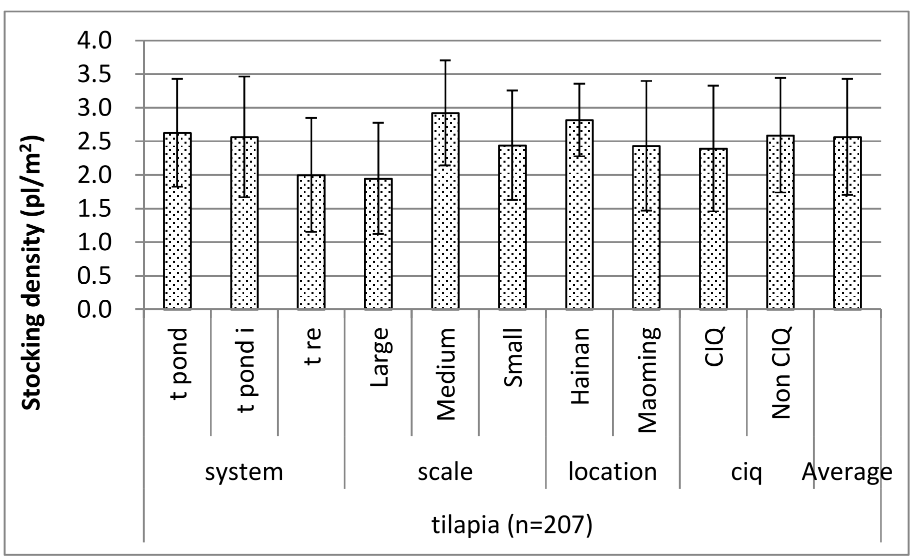


Figure 5.26 Tilapia stocking density of by farming systems, farm scales, farm location and CIQ registration status

(t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.6.4. Survival rate in grow-out period

The average shrimp survival rate was 64.06±17.96% (n = 168), and average tilapia survival rate was 83.94±13.36%A (n = 172). Tilapia had significant higher survival rate than shrimp (P<0.01), which can be partly explained by normal practice for tilapia farms to nurse fry in designated nursery pond before grow-out. The average survival rate was independent of farming scales and CIQ registration for both shrimp and tilapia farms, and independent of farm systems for tilapia farms (P>0.05). High-level shrimp farms had higher survival rates than medium and small-scale farms (P<0.01). Tilapia farms in Maoming had a higher survival rate than farms in Hainan (P<0.05) (Figure 5.27).

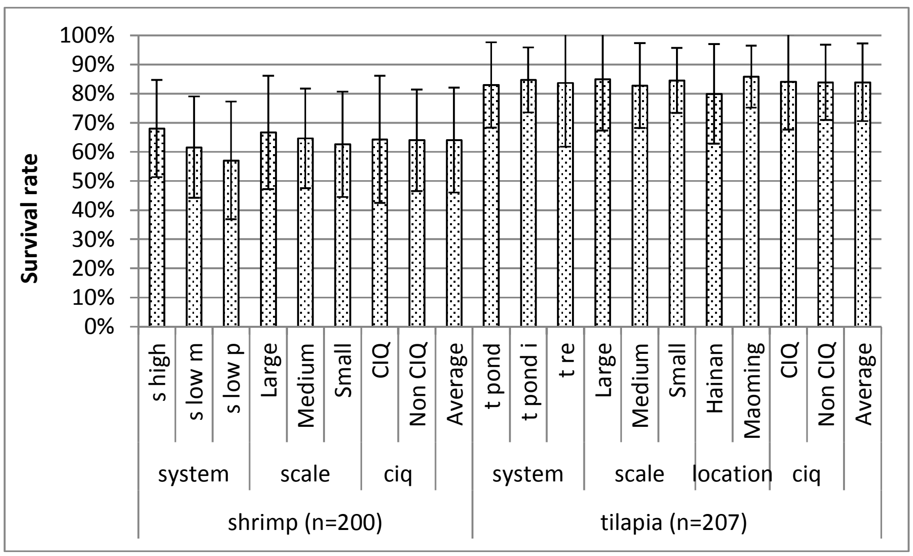


Figure 5.27 Survival rate by species, farming systems, farm scales, farm location and CIQ registration

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.6.5. Farm yields

Total farm yields were dependent on farming system, farm scale, farm location and CIQ registration (P<0.01). Large-scale shrimp and tilapia farms had the highest yields, and CIQ farms had higher yields than non-CIQ farms (P<0.01). Yields in high-level shrimp farms were greater than low-level farms (P<0.01). Reservoir tilapia farms had lower yields than tilapia non-integrated farms, which in turn were more than integrated farms (p< 0.01). Tilapia farms in Hainan also had lower yields than farms in Maoming (P<0.01) (Figure 5.28).

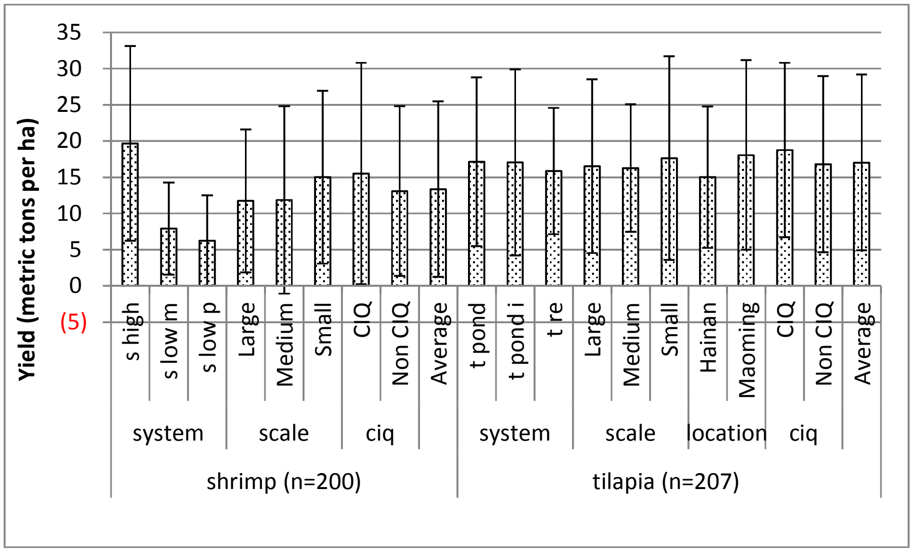


Figure 5.28 Farm total yields by species, farming systems, farm scales, farm location and CIQ registration

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.6.6. eFCRs

Both reported eFCR (by farmers) and calculated eFCR (calculated based on total feed use and total harvest) were analysed. Reported eFCR of shrimp farms (1.14±0.14, n=184) were significantly lower than calculated eFCR (1.35±0.56, n=148) (P<0.01) but there was no difference between tilapia farms (reported eFCR 1.61±0.28, n=150; calculated eFCR 1.72±0.58, n=153) (P>0.05).

For both shrimp and tilapia there were no differences in reported eFCR values among different scales and CIQ registration. Shrimp low-level monoculture had lower reported eFCR than high-level shrimp and shrimp low-level polyculture, integrated tilapia farms also had lower reported eFCR than tilapia non-integrated farms and reservoir tilapia farms, tilapia farms in Hainan also had higher reported eFCR than farms in Maoming (P<0.01).

No calculated eFCR difference was found between shrimp farms using different culture systems or having different CIQ registration status (P>0.05). Large-scale shrimp farms had higher calculated eFCRs than small-scale farms. Non-integrated pond tilapia farms had higher calculated eFCR than both integrated pond and reservoir farms (P<0.05). Medium farms had the highest calculated eFCR which was significantly higher than that of small-scale farms (P<0.05). Tilapia farms in Hainan also had higher calculated eFCR than that in Maoming (P<0.01). No difference was found between CIQ registration status (P>0.05).

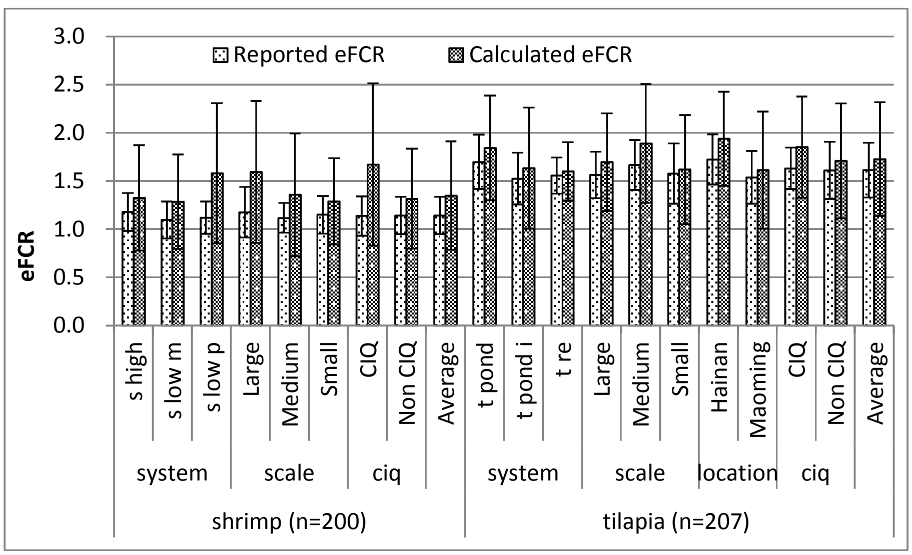


Figure 5.29 Reported eFCR and calculated eFCR by species, farming systems, farm scales, farm location and CIQ registration

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.6.7. Integrated crop agriculture

Only 5.15% (n = 21) farms were integrated with agriculture, mainly with fruit (n = 12), vegetable (n = 8), and rice (n = 1). Fruit included lychee (n = 3), carambola (n = 1), banana (n = 5), and longan (n = 3). The only farm integrated with rice production had rice planted in a separate field. Fruit was mainly planted in different fields (n = 7) or on pond dykes (n = 5), while vegetables were grown either on pond dykes (n = 6) or in different fields (n = 2). Fruit farming had area 95.6±146.5 mu (n = 7), rice 1 mu, and vegetable 0.84±1.03 mu. All rice and vegetable were reported as for household use and 50% fruit was reported for sale.

5.3.1.6.8. Integrated poultry and livestock

Only one farm, which was a low-level polyculture, medium scale, non CIQ farm, was integrated with duck farming. All reservoir tilapia farms and non-integrated tilapia farms did not have livestock integrated tilapia farming. Among integrated tilapia farms, most popular system was tilapia-pig integrated system (n = 69), followed by tilapia-duck (n = 7), tilapia-pig-chicken (n = 6), tilapia-pig-chicken-duck (n = 5), tilapia-pig-duck (n = 5) and tilapia-chicken (n = 3). In total, 44% (n = 91) of tilapia farms were integrated with pig farming, with an average number of 327.6±482.4 (n = 18) pigs per farm; tilapia farms had integrated duck farming with number 4066.7±5492.5; and 6.6% (n = 15) farms had integrated chicken farming with chicken number 676.33±937.88.

More small-scale tilapia farms were integrated than large and medium-scale farms ($P<0.01$). Eighty eight percent (n = 22) of large-scale and 70.1% (n = 54) of medium-scale tilapia farms were not integrated with crop or livestock farming, compared with only 27.6% (n = 29) of small-scale tilapia farms.

More farms in Maoming were integrated than Hainan (P<0.01). Only 2.8% (n = 2) of farms in Hainan are integrated with agriculture compared with 74.1% (n = 102) in Maoming.

Few CIQ farm 8% (n = 2) were integrated, and 54.9% (n = 102) non-CIQ farms were integrated.

Pigs in the integrated system were only for sales, while chicken were for both household consumption and sales (n = 7), for sales (n = 6) and for household use (n = 2). Duck were also mainly for sale(n = 17), with only one farm reporting duck also being reared for household consumption.

5.3.1.7. Economic analysis

5.3.1.7.1. Feed price

Low-level shrimp polyculture farms had lower feed cost because they mixed shrimp feed with lower priced feed for other species, large-scale shrimp farms also had lower feed price than small and medium-scale farms (P<0.05). Tilapia feed was cheaper in Maoming than in Hainan, and small-scale and integrated tilapia farms had cheaper feed as most were based in Maoming (P<0.01). No difference was found among CIQ registration status (P>0.05) (Figure 5.30).

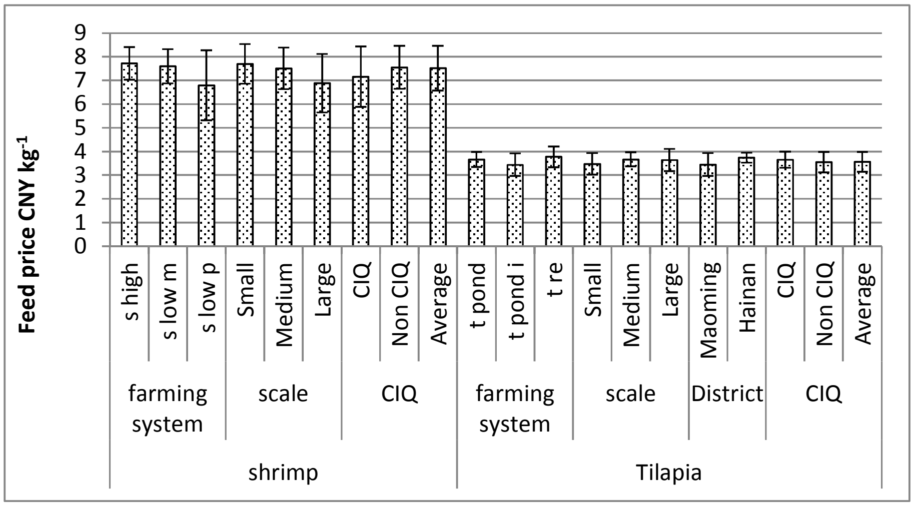


Figure 5.30 Feed price by species, farming system, farm scale CIQ registration and farm location

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.7.2. Seed price

High-level shrimp farms had higher seed price than low-level shrimp farms, and small-scale farms had lower seed price than medium and large-scale farms. CIQ farms had higher seed price than non-CIQ farms ($P<0.05$). Tilapia seed price in Hainan was cheaper as Hainan was one of major seed producing area ($P<0.01$), and medium-scale farms had cheaper seed ($P<0.05$) as most medium-scale farms were in Hainan. No difference was found among different tilapia farming systems and tilapia CIQ registration status ($P>0.05$) (Figure 5.31).

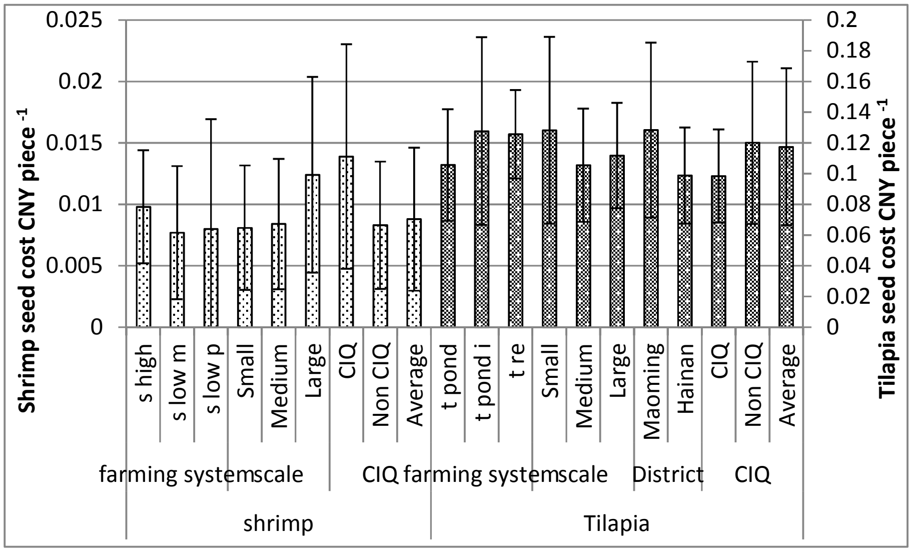


Figure 5.31 Seed unit cost by species, farming system, farm scale CIQ registration and farm location

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.7.3. Electricity price

Electricity price was mainly dependent on local electricity supply price policy, which was CNY 0.72±0.16 kWh^{-1} in Zhanjiang, 0.65±0.06 in Maoming and 0.76±0.09 in Hainan. Because there were more medium-scale non-integrated farms in Hainan, electricity price was higher for medium-scale farms and non-integrated farms ($P<0.01$), but no difference between CIQ registration status ($P>0.05$).

5.3.1.7.4. Harvest Size

Average shrimp size at harvest was 12.64±5.13 g (n = 183), while average tilapia size at harvest was 593.4±113.3 g (n = 197). Average size at harvest was independent of farming system for both shrimp and tilapia farms and independent of farm location and CIQ registration for tilapia farms ($P>0.05$). Large-scale shrimp farms and CIQ shrimp farms produced larger shrimp than medium and small-scale shrimp farms and non-CIQ shrimp farms ($P<0.01$). Large-scale tilapia farms and reservoir farms produced bigger size fish than medium and small-scale tilapia farms and pond farms (P<0.01) (Figure 5.32).

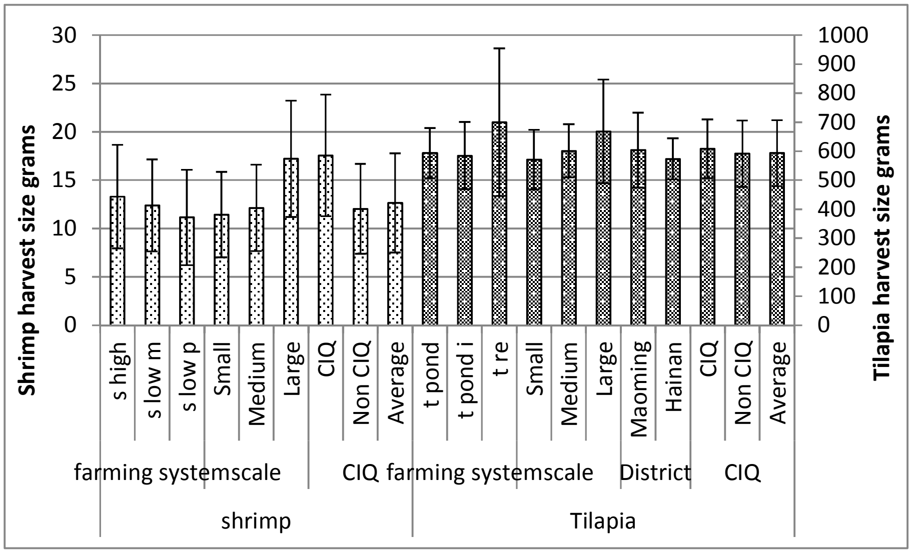


Figure 5.32 Harvest size by species, farming systems, farm scales, farm location and CIQ registration (Unit: g)

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.7.5. Farm gate sales price

The average shrimp sales price was CNY 23.02±10.92 kg^{-1} (n = 173), and average tilapia sales price was CNY 7.67±0.96 kg^{-1} (n = 197).

Both high- and low-level monoculture farms realised higher farm gate price than low-level shrimp polyculture farms, and large-scale shrimp farms got higher price than medium and small-scale farms (P<0.05). No difference in farm gate price were observed between CIQ farms and non-CIQ farms (P>0.05).

Reservoir tilapia farms and non-integrated tilapia farms reported higher price than integrated farms (P<0.01). Small-scale farms also got lower price than medium and large-scale farms as most integrated farms were small-scale. Farm gate price in Hainan was higher than that in Maoming ($P<0.05$), and CIQ farms report higher price than non-CIQ farms ($P<0.01$) (Figure 5.33).

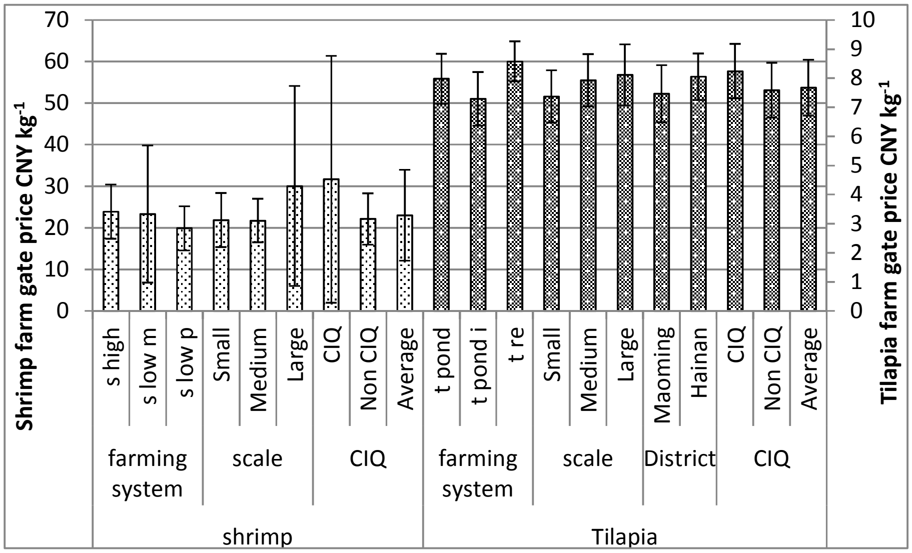


Figure 5.33 Sales price by species, farming systems, farm scales, farm location and CIQ registration (Unit: CNY)

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.7.6. Farm income

Average annual farm income was CNY 83,631±440,185 for shrimp farms and CNY 166,928±503,028 for tilapia farms, there being no statistically difference between the two ($P>0.05$). Farm income of low-level shrimp monoculture farms was lower than that of high-level shrimp farms and low-level shrimp polyculture farms. Small-scale farms had lower income than large and medium-scale farms ($P<0.05$). Tilapia integrated farms and small-scale farms reported lower income than other farms ($P<0.05$), but no difference was found between tilapia farms in Hainan and Maoming ($P>0.05$). For both shrimp and tilapia farm no difference between CIQ registration status ($P>0.05$) (Figure 5.34).

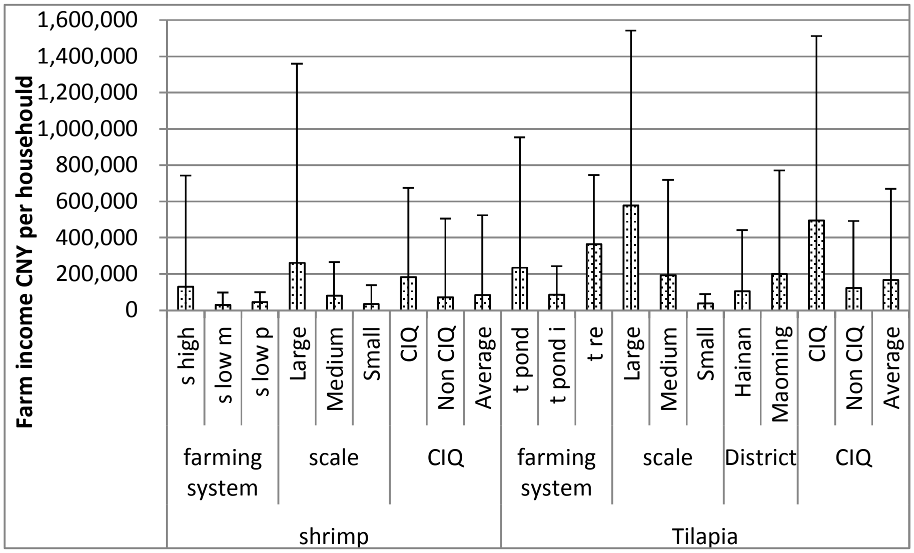


Figure 5.34 Farm income of shrimp and tilapia farms by farming system, farm scale, farm location and CIQ registration

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.7.7. Farm primary income source

The primary income sources of shrimp farms was aquaculture 88.5% (n = 177), followed by salaried employment 6.5% (n = 13), other business 2.5% (n = 5), agriculture 1.5% (n = 3), and remittances from family members 0.5% (n = 1). This did not differ with farming system, scale or CIQ registration (P>0.05).

The primary income source of tilapia farms was aquaculture 87.0% (n = 180), followed by agriculture 9.2% (n = 19), other business 2.4% (n = 5) and salaried employment 1.4% (n = 3). Small-scale integrated tilapia farms in Maoming district were more likely to depend on agriculture as primary income sources, compared with other farms (P<0.05). No significant difference was found between CIQ and non-CIQ tilapia farms (Figure 5.35).

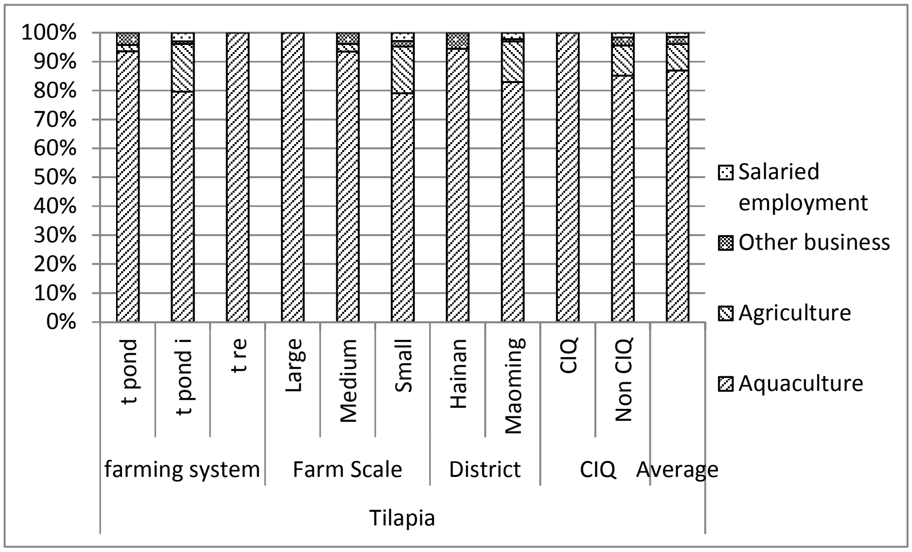


Figure 5.35 Primary farm income sources of tilapia farms by farming system, farm scale, farm location and CIQ registration.

(t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.7.8. Farm secondary income source

Sixty per cent (n = 120) of shrimp farms had no secondary income source, 16% (n = 32) had salaried employment as secondary income source, followed by 9.5% (n = 19) aquaculture, 8.5% (n = 17) other business, and remittances from family members 1% (n = 2), no difference among different farming system, scale, and CIQ registration (P>0.05).

Fifty six per cent (n = 116) of tilapia farms had no secondary income sources, 18.8% (n = 39) took agriculture as secondary income source, followed by aquaculture 12.6% (n = 26), other business 6.3% (n = 13), salaried employment 5.8% (n = 12) and remittances 0.5% (n = 1). Medium-scale tilapia pond farms, farms in Hainan and CIQ farm do not have a secondary income source, and small-scale integrated tilapia farms in Maoming district were more likely to depend on agriculture as secondary income source comparing with other farms (P<0.01) (Figure 5.36).

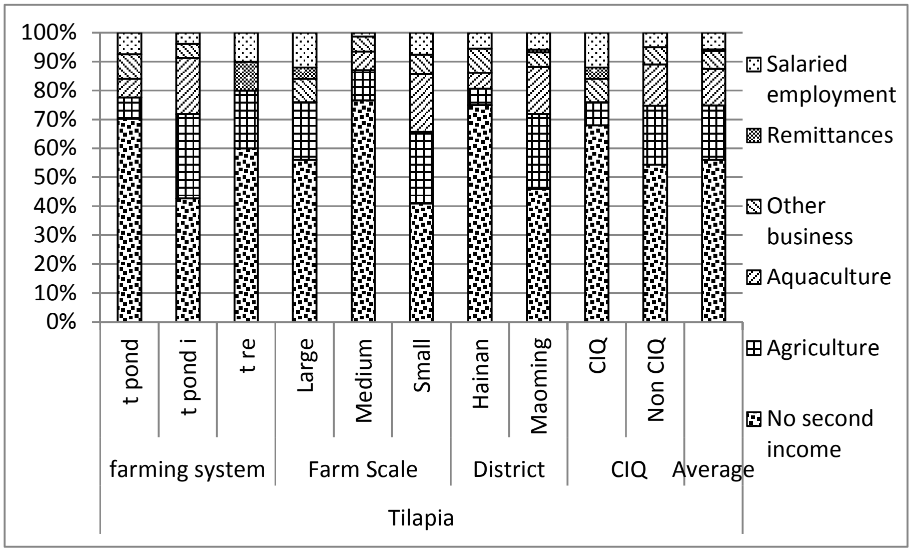


Figure 5.36 Secondary farm income sources of tilapia farms by farming system, farm scale, farm location and CIQ registration.

(t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.7.9. Part-time and full-time farmer

All farmers were divided into part-time and full-time based on income sources. Full-time farmers obtained 100% of their income from aquaculture last year, while part-time farmers had other income sources.

Sixty eight per cent (n = 136) of shrimp farmers were full-time and no difference was found between different farming systems, scales, and CIQ registration status (P>0.05).

Sixty per cent (n = 125) of tilapia farmers were full-time. More non-integrated tilapia pond farmers, medium-scale farmers, and farmers in Hainan were full-time (P<0.05) and no significant difference was found between CIQ and non-CIQ tilapia farmers (P>0.05) (Figure 5.37).

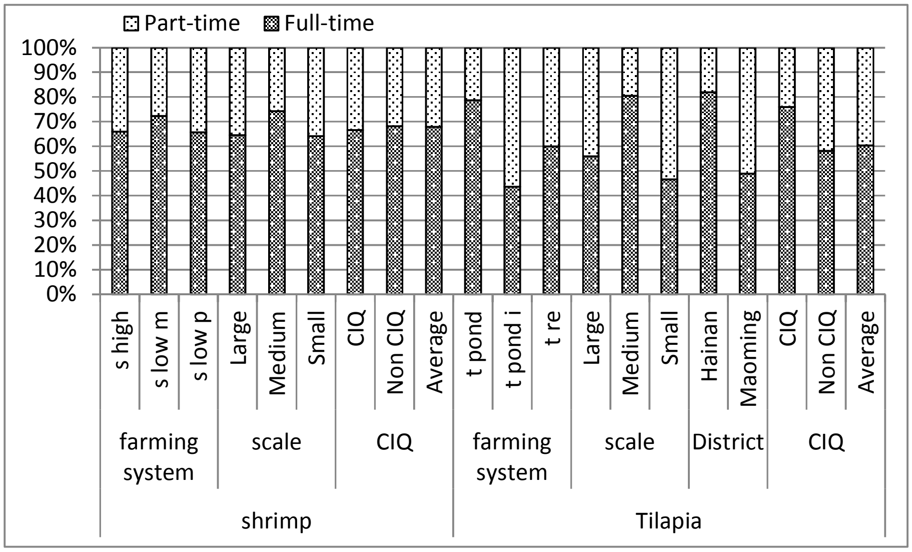


Figure 5.37 Primary farm income sources of tilapia farms by farming system, farm scale, farm location and CIQ registration.

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

5.3.1.8. Farm productivity and efficiency

5.3.1.8.1. Farming species and productivity and efficiency

Tilapia farms had higher labour productivity in both production and value output, higher land productivity in production terms, and higher energy efficiency than shrimp farms, but land productivity in value output and feed efficiency were lower than in shrimp farms ($P<0.01$) (Figure 5.38).

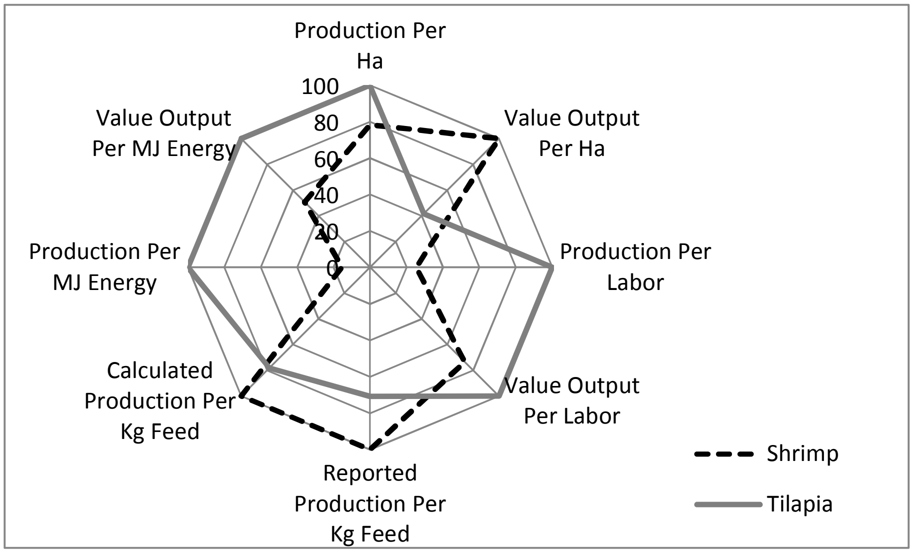


Figure 5.38 AMOEBA analysis of shrimp and tilapia farming productivity and efficiency

(Numbers are percentage indicates relative values of different species comparing to the highest value in same group)

5.3.1.8.2. Farm scales and productivity and efficiency

Small shrimp farms had the highest land productivity in production terms and the highest calculated feed efficiency, but the lowest in labour productivity in both production and value output terms. Although small-scale farms performed well in terms of land productivity in production terms, in value terms they were slightly lower than large-scale farms, mainly due to the better terms of trade (and higher farm gate price) enjoyed by larger enterprises. Medium-scale shrimp farms had better performance in energy efficiency, and had equally high labour productivity in both production and value output terms (Figure 5.39).

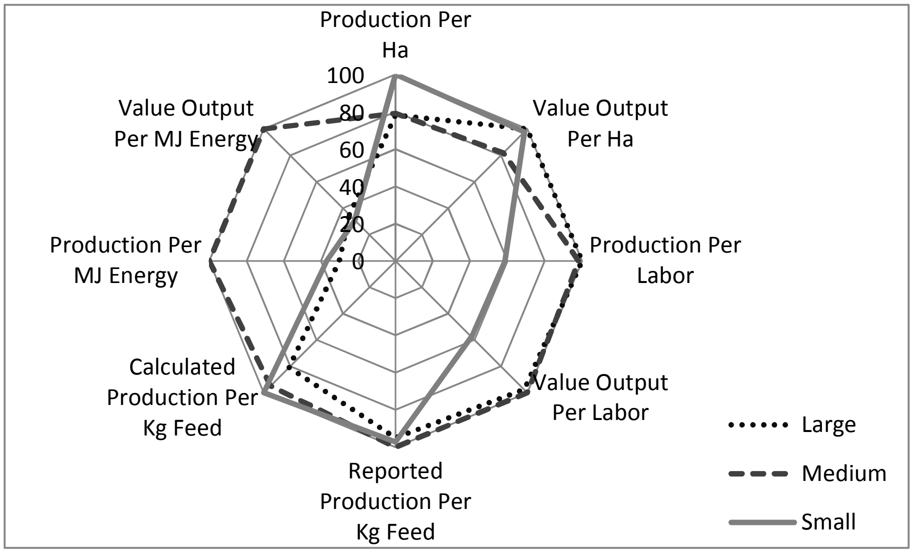


Figure 5.39 AMOEBA analysis of shrimp farming productivity and efficiency of different farming scales

(Numbers are percentage indicates relative values of different farm scales comparing to the highest value)

Large-scale tilapia farms had the highest energy efficiency and the highest land productivity in value terms. Medium-scale farms performed the best on labour productivity in both production and value output terms. Small-scale farms had the highest land productivity in production terms and the highest feed efficiency in terms of both production and value, but the lowest labour productivity in terms of both production and value and the lowest energy efficiency (Figure 5.40).

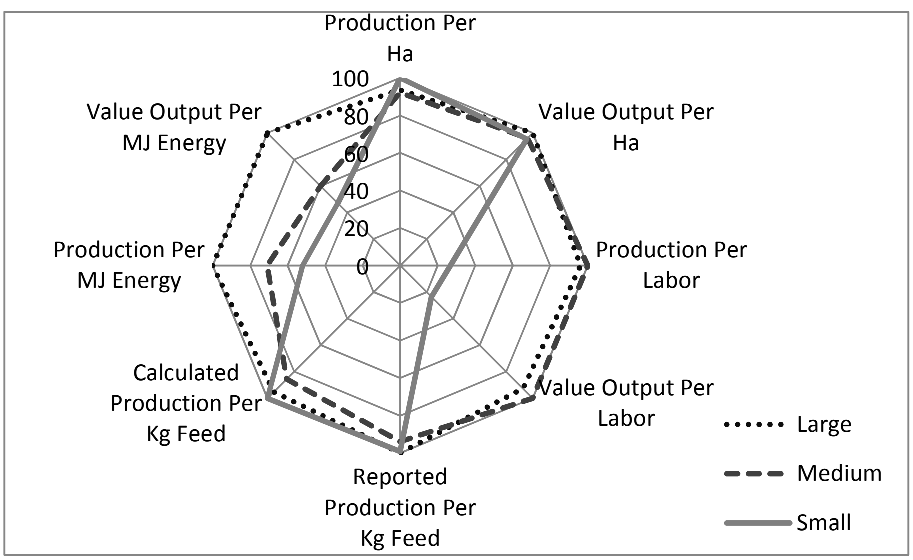


Figure 5.40 AMOEBA analysis of tilapia farming productivity and efficiency of different farming scales

(Numbers are percentage indicates relative values of different farm scales comparing to the highest value)

5.3.1.8.3. Farming systems and productivity and efficiency

High-level shrimp farming system had higher labour and land productivity, but lower energy efficiency than low-level shrimp farming systems (P<0.01). Shrimp low-level polyculture had the highest energy efficiency, but lowest land productivity in both production and value output. Shrimp low-level monoculture had the highest feed efficiency, but lowest labour productivity (Figure 5.41).

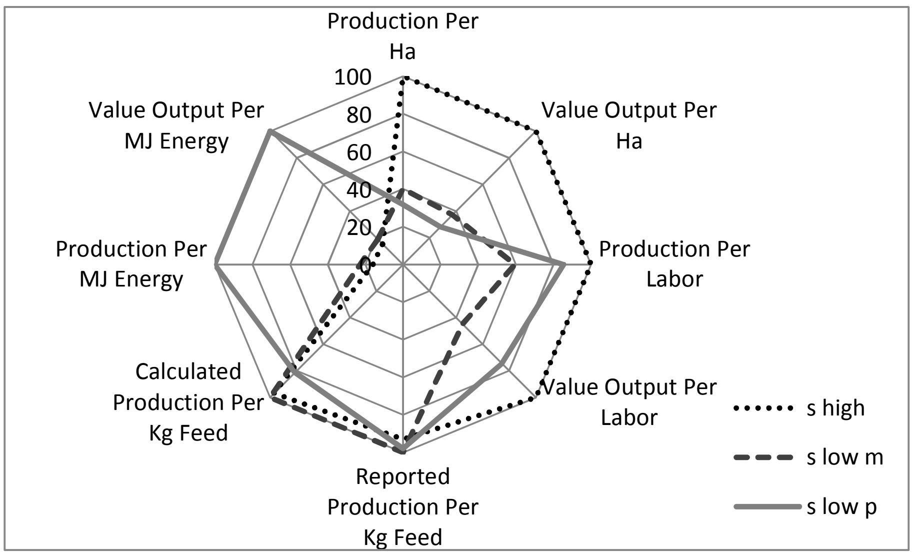


Figure 5.41 AMOEBA analysis of shrimp farming productivity and efficiency of different farming systems

(s high= high-level shrimp farms, s low m= low-level shrimp monoculture farms, and s low p = low-level shrimp polyculture farms. Numbers are percentage indicates relative values of different farming systems comparing to the highest value in same group)

Reservoir tilapia farms had the highest land productivity in value output, the highest labour productivity in both production and value output, the highest energy efficiency, and the highest calculated eFCR among all farming systems than tilapia pond farms. Tilapia pond farming systems performed worse on the basis of most indicators, only better in land productivity in production terms but the difference was quite modest. Integrated tilapia farms have lowest productivity and efficiency in most of indicators, especially labour productivity and energy efficiency (Figure 5.42).

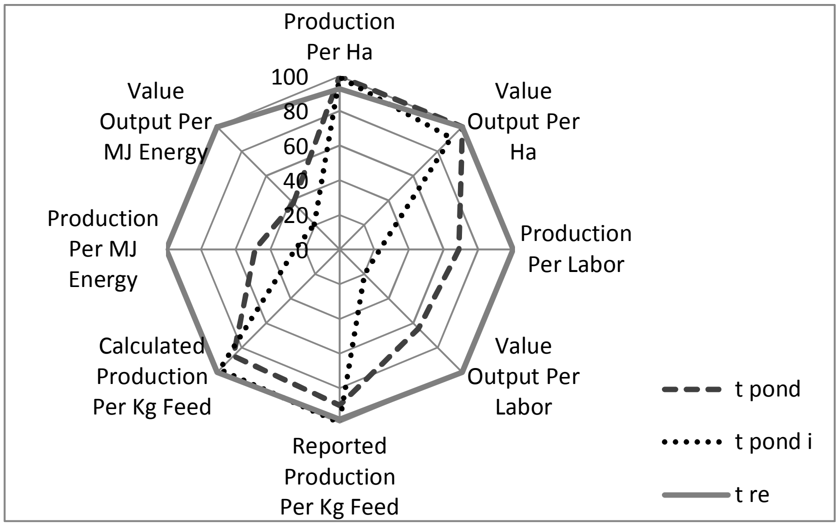


Figure 5.42 AMOEBA analysis of tilapia farming productivity and efficiency of different farming systems

(t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms. Numbers are percentage indicates relative values of different farming systems comparing to the highest value in same group)

5.3.1.8.4. CIQ registration and productivity and efficiency

CIQ shrimp farms performed better in terms of land and labour productivity but had similar reported feed efficiencies to non-CIQ farms. Non-CIQ farms had better energy efficiency and better calculated feed efficiency than CIQ farms (Figure 5.43).

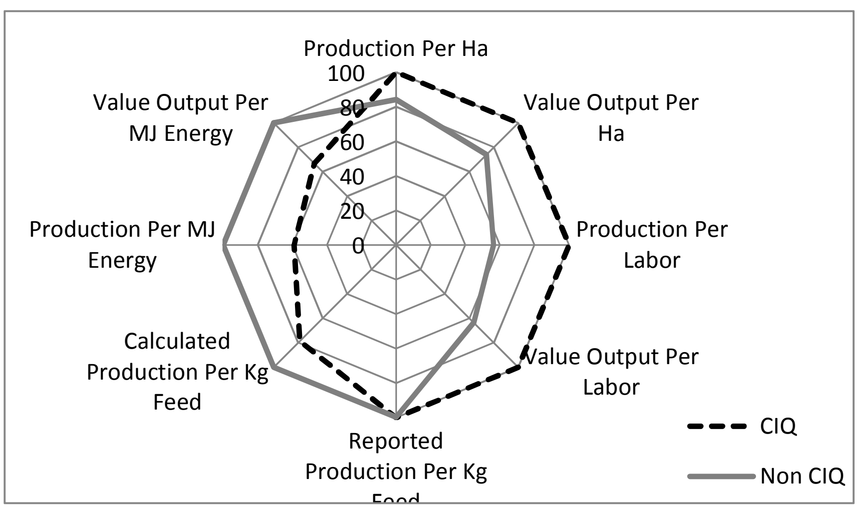


Figure 5.43 AMOEBA analysis of shrimp farming productivity and efficiency by CIQ registration status (Numbers are percentage indicates relative values of different CIQ registration status comparing to the highest value in same group)

CIQ tilapia farms eclipsed non-CIQ farms in most indicators, but had lower calculated feed efficiency (Figure 5.44).

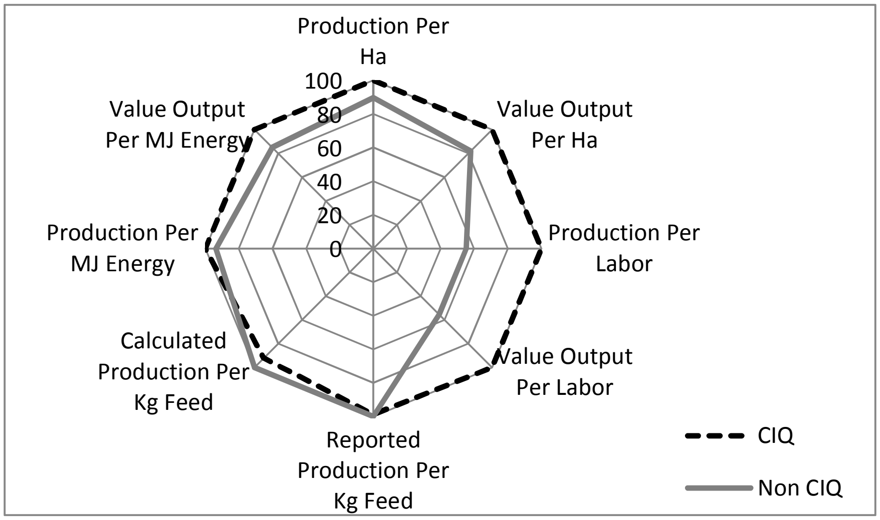


Figure 5.44 AMOEBA analysis of tilapia farming productivity and efficiency by CIQ registration status

(Numbers are percentage indicates relative values of different CIQ registration status comparing to the highest value in same group)

5.3.1.8.5. Farm location and productivity and efficiency

Tilapia farms in Hainan performed better in terms of labour productivity and energy efficiency, but tilapia farms in Maoming performed better in land productivity and feed efficiency (Figure 5.45).

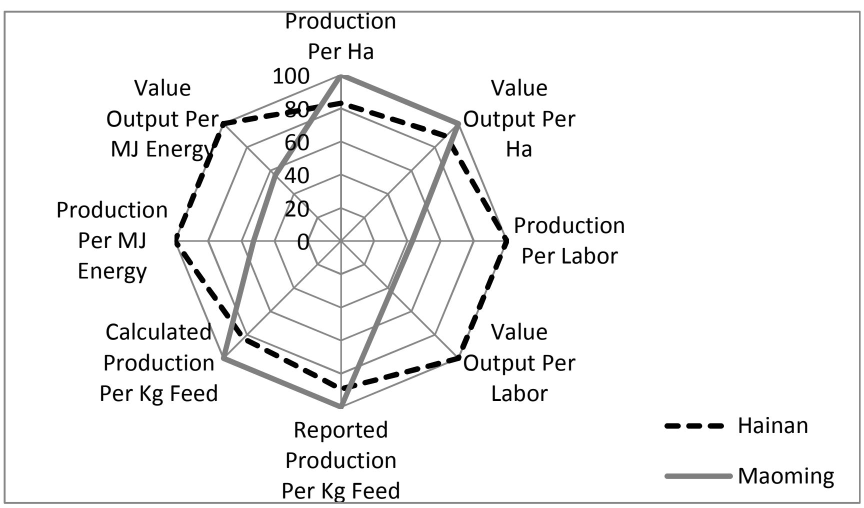


Figure 5.45 AMOEBA analysis of tilapia farming productivity and efficiency by producing areas

(Numbers are percentage indicates relative values of different farm location comparing to the highest value)

5.3.2. Follow-up survey result

5.3.2.1. Survey response

Among the 407 farms in the baseline survey, 164 (37.1%) farms were interviewed as part of the follow-up survey, including 74 shrimp farms and 90 tilapia farms. The reasons for non-response were mainly related to poor connectivity to initial phone calls for various reasons (Figure 5.46).

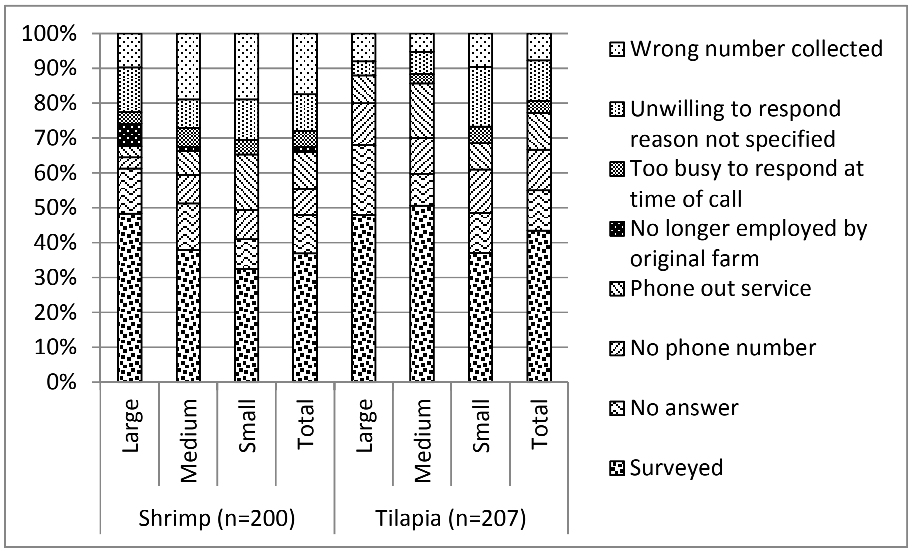


Figure 5.46 Survey response rate and non-response reasons

5.3.2.2. Farm profiles

Farm and interviewee profiles were analysed in Figure 5.40 for shrimp and tilapia farms.

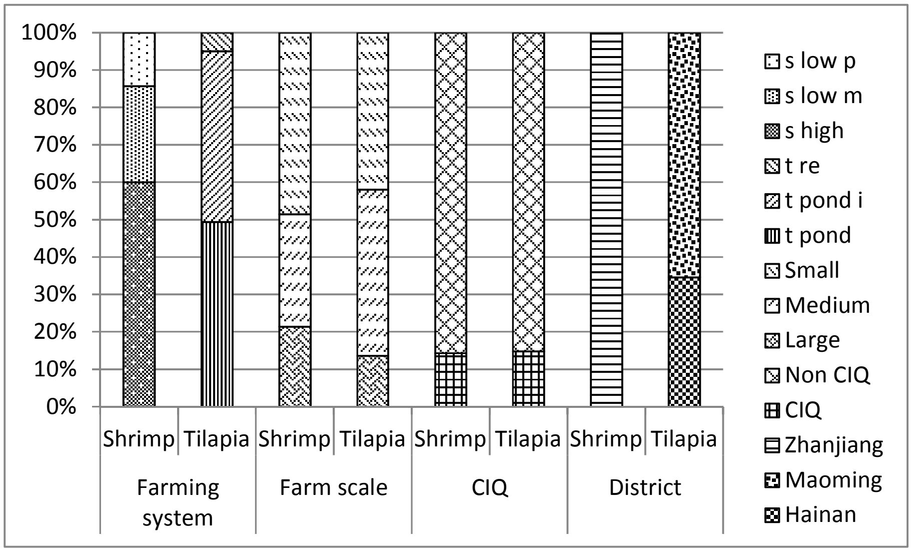


Figure 5.47 Farm and interviewee profiles of shrimp and tilapia farms

5.3.2.3. Farm Change Status

More shrimp farms reported having stopped or were planning to stop permanently than tilapia farms, and more tilapia farms reported no significant change with their farms (P<0.01) (Figure 5.48). No difference was found among different shrimp and tilapia farming systems, farm scales, CIQ registration and farm location (P>0.05).

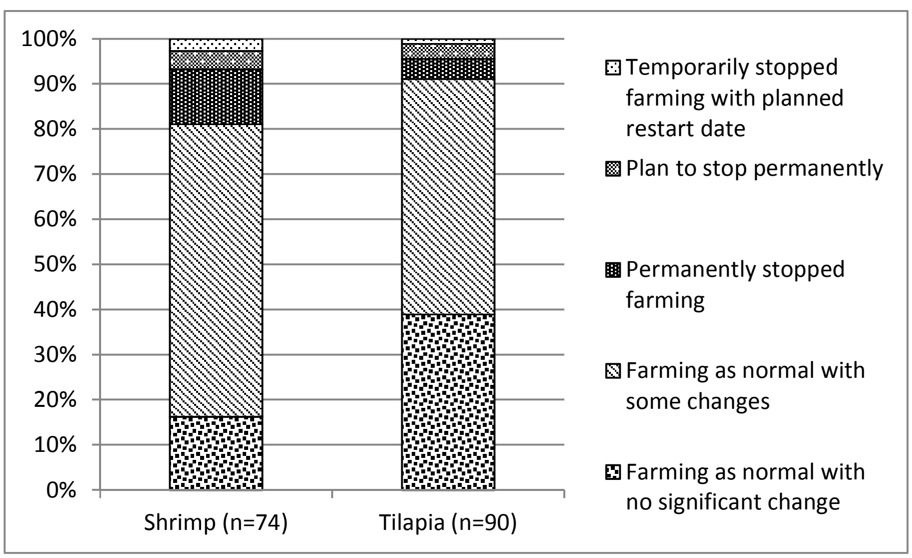


Figure 5.48 Farm change status of shrimp and tilapia farms

5.3.2.4. Major farm changes

The most common reported major farm change was farm gate price fluctuation (n = 57), which included both price increase and decrease, followed by stocking density changes (n = 19), labour change (n = 12), scale change (n = 7), infrastructure improvement (n = 9), species diversification (n = 8), more disease (n = 7) and other changes (Figure 5.49). The increased farm gate price was only reported by shrimp farms and decreased price only by tilapia farms (P<0.01). More shrimp farms reported infrastructure improvements and more diseases than tilapia farms (P<0.01), and only tilapia farms reported species diversification (P<0.05).

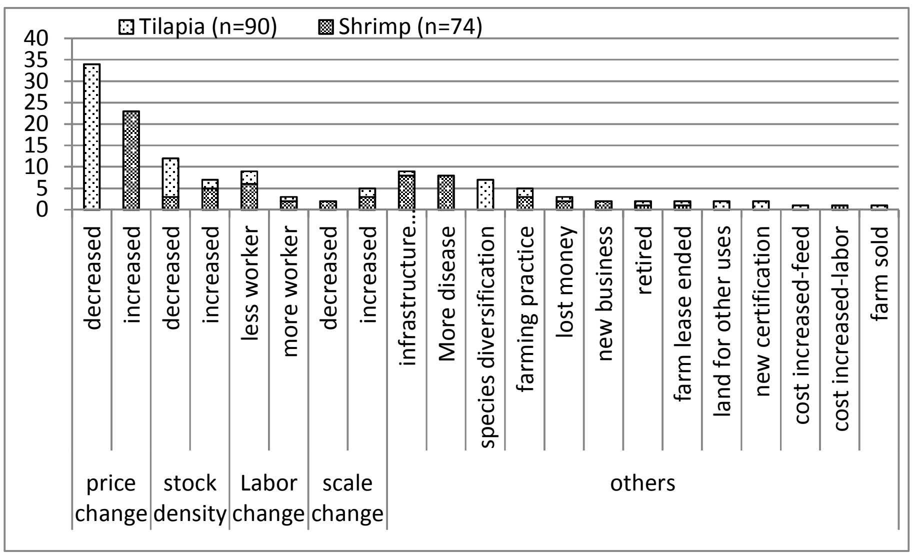


Figure 5.49 Farm Change details of shrimp and tilapia farms

5.3.2.5. Future changes planned

No shrimp farms were considering changing their main species or diversification of the species farmed. In contrast, seven tilapia farms reported plans to change primary species, four reported plans to diversify farming species, and one planned to reduce feed inputs. Three shrimp farms and three tilapia farms planned to stop farming, and one shrimp and one tilapia farm to reduce stocking densities. Surprisingly, one shrimp farm planned to cooperate with other farmers to improve production, although no shrimp farmers' cooperative was found in the survey (Figure 5.50). No differences were found among different shrimp and tilapia farming systems, farm scales, CIQ registration and farm location (P>0.05).

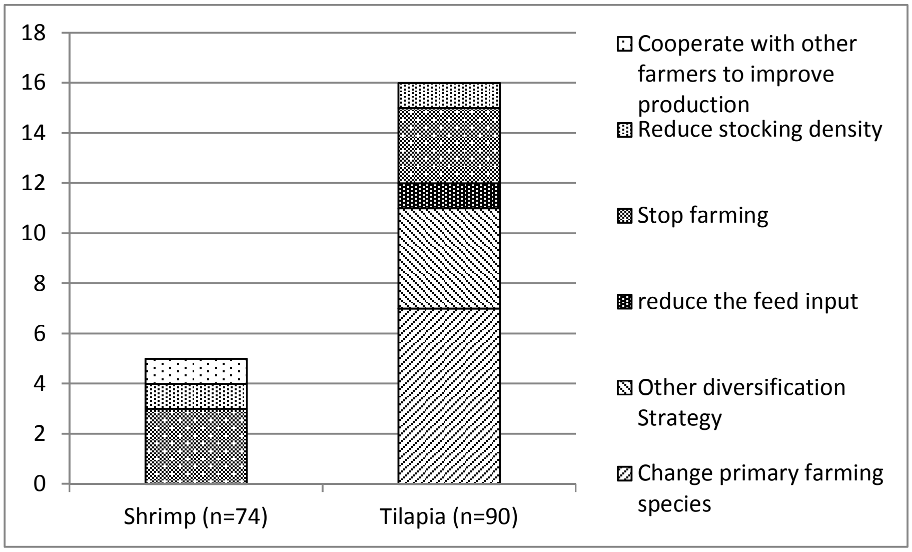


Figure 5.50 Future changes in plan of shrimp and tilapia farms

5.3.2.6. Reasons for stopping farming

Nearly 70% (68.2%) of farms who stopped farming reported that disease was one of major reasons for doing so, followed by stock losses, low sale price, poor seed quality and other reasons. More shrimp farms stopped because of stock losses and poor seed quality than tilapia farms, and more tilapia farms stopped because of low sale prices than shrimp farms (P<0.05). No difference was found among different shrimp and tilapia farming systems, farm scales, CIQ registration (P>0.05). However, more tilapia farms in Hainan stopped because of lower sale prices than tilapia in Maoming (P<0.05).

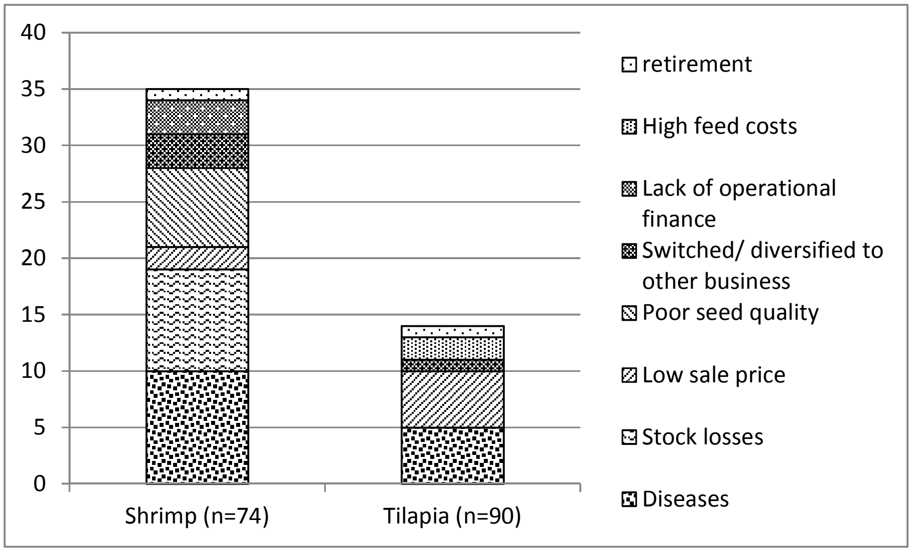


Figure 5.51 Reasons of shrimp and tilapia farms stopping production

5.3.2.7. Farming practice and production changes

Major farming practice and production changes included stocking density changes, species diversification, infrastructure improvements, total culture area and number of ponds changed, and other changes (Figure 5.52). All species diversification was reported by tilapia farms and all infrastructure improvements were by shrimp farms ($P<0.01$). There were no differences for stocking density changes and total culture area and number of pond changes between shrimp farms and tilapia farms ($P>0.05$). No differences were found among different shrimp and tilapia farming systems, farm scales, CIQ registration and farm location ($P>0.05$).

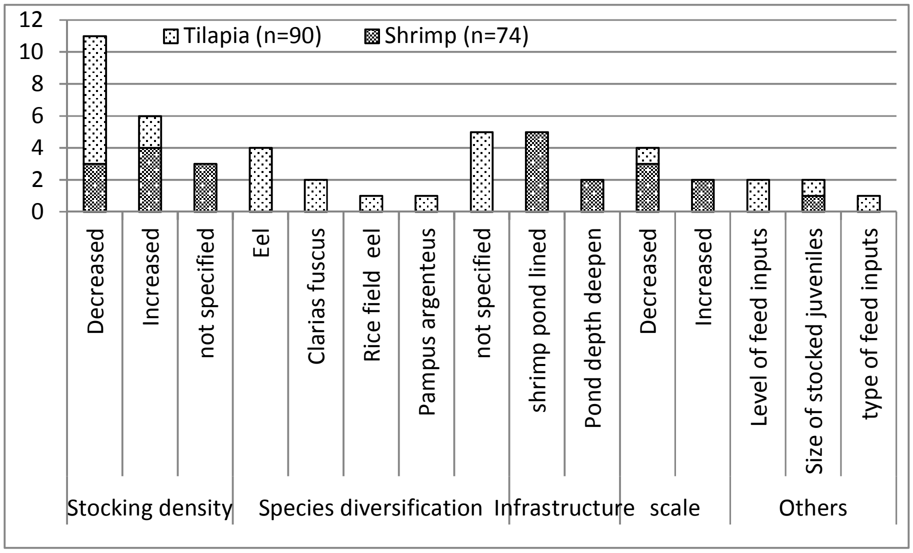


Figure 5.52 Farm changes of shrimp and tilapia farms

Two shrimp farms reported an average -30.00% stocking density decrease, and four shrimp farms reported 53.3±53.4% stocking density increase. Seven tilapia farms reported decreases in stocking density averaging 28.3±16.1% and two reported stocking density increases (mean 44.5%). Three shrimp farms reported mean 24.7±4.5% total culture area decrease and two reported 36.5% total culture area increase.

5.3.2.8. Post-Harvest Changes

The most important post-harvest change was price fluctuation and more tilapia farms reported farm gate price decreases than shrimp farms ($P<0.01$). More than 80% (81.5%; n = 44) shrimp farms reported increased farm gate price, 16% (n = 9) reported decreases and 1.9% (n = 1) reported price volatility. All tilapia farms (n = 79) reported farm gate prices decreased. However, the statistics show the price reported by tilapia farms in the follow-up survey was 8.11±0.295 CNY kg^{-1} (n = 67), which was also significantly higher (5.7%) than tilapia farms reported 7.67±0.963 CNY kg^{-1} (n = 197) in the baseline survey. Shrimp farms reported average farm gate price at 36.29±7.976 CNY kg^{-1} (n = 52) in the follow-up survey, which also significantly higher (57.6%) than they reported

23.02±10.917 CNY kg^{-1} (n = 173) in the baseline survey.

5.3.2.9. Farm investment

Most farms didn't make major investments, one tilapia farm had invested in hatchery facilities, and another two tilapia farms renovated their ponds for eel farming. One shrimp farm leased more ponds and expanded its farming area, while one tilapia farm leased out ponds and reduced farming area. As part of responses to investment questions, farmer reported labour changes; nine shrimp farms and four tilapia farms reported a fall in the number of full-time labourers while one shrimp farms and two tilapia farms reported increases.

5.3.2.10. Aquaculture within livelihood portfolios

Compared to the situation at the time of the baseline survey, the follow-on survey found both shrimp and tilapia farms changed towards a focus on aquaculture as the primary income source. (Figure 5.53)

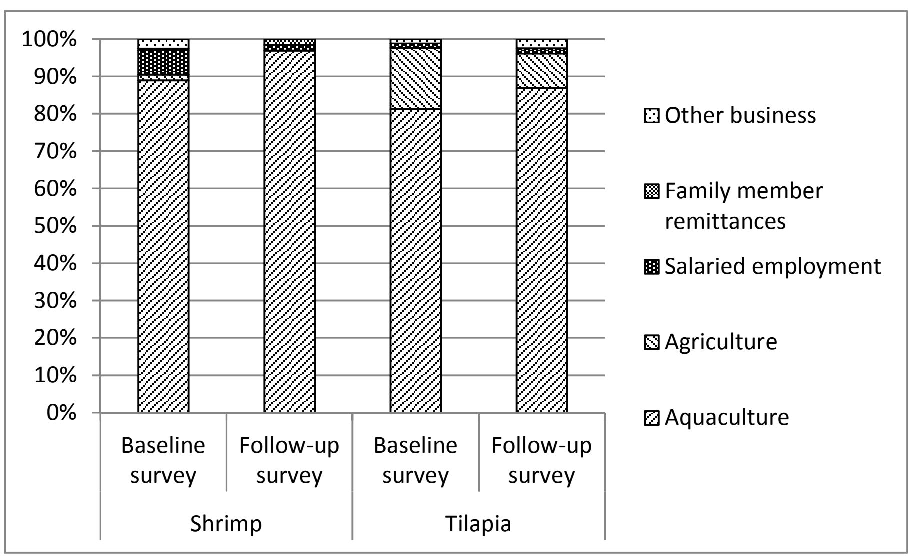


Figure 5.53 Comparing of primary farm income source between baseline survey and follow-up survey

5.4. Discussion

5.4.1. Farm scale profiles

Although farm scale was an independent stratification variable in the survey design, it was adjusted afterwards to balance farm numbers in each farm scale category. Farm scale indicators needed to be considered together to differentiate farm scale. Reliance on any single farm scale indicator would be likely to cause overlap between different farm scales, due to the complex farming practice and intensification level. For example the water area of medium-scale, high-level shrimp farms ranges from one ha to six ha and large-scale higher than two ha, while medium-scale farms require less than seven farm labours and large-scale requires seven or more.

Farm areas, including land and water area, and amount of farm labour, including paid and unpaid were effective indicators to distinguish farm scales. However, farm ownership and management were much less effective farm scale indicators due to highly diversified farming practice. The existence of a farm trade name was correlated with CIQ registration, and a much higher proportion of large-scale farms had trade names than medium and small-scale farms. Previous research suggested that subsistence and artisanal farmers were more likely to use small sized ponds and less intensified farming system due to limited resources (Edwards & Demaine 1998). This study shows large tilapia farms were more likely use large sized ponds; however, pond size on shrimp farms was mainly dependent on farming system, and high-level farms usually had smaller ponds than low-level farms.

5.4.2. Performance comparison of different farm scales

Many studies have shown an inverse relationship between farm scale and productivity. Small-scale farms can achieve higher land and capital productivity than large-scale farms (Heltberg 1998; Belton *et al.* 2012). Sustainability of small-scale farms was linked to their high-levels of species diversity, nutrient cycling, capacity (total production) and economic efficiency (Little & Edwards 2003). Small-scale farms have lower production costs than large-scale farms (Roth 2002), and they are more resilient and adaptable to calamities and changes (Kongkeo & Davy 2010).

The agriculture sector in Asia is still dominated by small-scale farms; average agriculture farm size actually decreased between 1960s and 1990s (Hazell *et al.* 2007). The growth rate of large-scale farms dominating agriculture in countries like Brazil was lower than small-scale farms dominating agriculture in Asian countries such as China and Vietnam in recent years (Hazell *et al.* 2007), although this is possibly caused by the sustained rapid economic growth in these Asia countries.

However, small-scale farms tend to use labour intensive technologies rather than capital intensive machines, their capital productivity is higher and labour productivity is lower than large-scale farms. From a value chain perspective, the higher productivity of small-scale farms is not sufficient to counter the inefficiencies in logistics due to poor linkages to market as well as constraints relating to finance, capacity, and infrastructure. Current techniques and social economic development have made the rapid adoption of technology, access to finance, and high-speed logistics more important, and in the process given large-scale industrialized agriculture a substantial advantage over the small-scale farms (Wegner & Zwart 2011).

The difference between small-scale and large-scale farms is not only scale but also different uses of labour and other inputs, and access to technologies, markets, information, that characterise the players in agriculture (Table 5.8).

Table 5.8 Pros and Cons of small and large-scale farms

Scale	Pros	Cons
Small	Better knowledge of local contexts.	Informal and personalised operations.
	Generating employment for rural youth.	Lack of access to assets and capital, higher transaction costs, problems in adapting and responding quickly to market developments.
	Contribution to food security in undeveloped areas.	Small-volume trading, variable and sub-standard quality products to sell, and lack of market information and links with buyers in the marketing chain.
	Multiplayer effects in the rural economy.	Vulnerability to climatic and price shocks, limited use of modern risk-management tools.
		Unfair competition in local, regional, and global markets.
		Poor organisation and lack of bargaining power in the marketplace to influence national, regional, and global agricultural policies.
		Possible negative consequences for the environment.
Large	Potential to reverse long-standing under-investment in agriculture in countries with large areas of fertile land. According	Lack of attention to existing land users
	High quality standards assured.	Negative distributional and gender effects
	Economies of scale.	Public-sector constraints on the collection of land taxes and monitoring of investors' compliance with agreements made with local communities.
	Provision of access to markets and technologies to smallholders.	Rent-seeking behaviour/short-term interest.
	Employment generation.	Negative environmental impacts.
	Higher export revenues.	
	Support for social infrastructure.	

(source: Wegner & Zwart, 2011)

In terms of Belton et al's. (2012) farm typology, most tilapia and shrimp farms in this study could be defined as either quasi-capitalist or capitalist forms of aquaculture. No subsistence farmer was found in the survey, all farmed seafood being destined for the market.

It was reported that large-scale farms could achieve higher productivity than small-scale farms

(Wegner & Zwart 2011), and attain slightly higher price for their produce than small-scale farms (Roth 2002). This study found both shrimp and tilapia farms, large-scale and medium-scale farms achieved much higher labour productivity than small-scale farms. Although small farms were slightly higher in land productivity in production terms than medium and large-scale farms, there was less difference in land productivity in value output term, mainly due to the lower farm gate prices available to small-scale farms. The labour productivity and employment impacts are important indicators of aquaculture's contribution to poverty reduction in developing country agriculture, where labour supply is still abundant (Ahmed & Lorica 2002). The large difference in labour productivity between small-scale farms and medium and large-scale farms suggests that smaller land and water holdings are a major limitation factor for small-scale farmers. Our productivity comparison shows that farms need to be at least of medium-scale to achieve certain labour productivity. The high proportion of integrated small-scale tilapia farms can be explained by the low labour productivity of aquaculture alone, which could not fully utilize labour, but encouraging farmers to diversify through associated intensive livestock farming. Profit per unit area of land is more important for land limited farmers, instead of benefit cost ratio (Edwards 2011a), this may explain the higher land productivity in production term of small-scale farms.

Substantial overall increases in production have led to large reductions in price and the only way for companies to survive and remain profitable is to reduce production costs through productivity growth (Asche *et al.* 2008). Production cost and farm scale were associated according to U-shaped average cost (AC) curve theory, where an optimal farm scale exists to achieve the lowest cost (Kvaløy & Tveterås 2008). Although no cost benefit was undertaken in this study, the lower labour productivity of small-scale farm reveals they were in another end of the U-shaped average cost curve and average cost (or opportunity cost) is inevitably high.

However, the land productivity analysis only covered farm water area, and did not include the so called '*ghost hectares*' required to supply resources, which are significantly higher than land occupied by aquaculture operations themselves (Beveridge *et al.* 1994; Belton *et al.* 2010). Nonetheless, comparing land productivity between different farming systems for one farm species is still valuable. Broader analysis tools such as LCA are needed in order to better understand overall land productivity.

Small-scale farms tend to think of farm work in terms of supporting a household livelihood rather than financial returns for the hours worked, and are thus more likely to work hard and manage their farms efficiently. This is the root of productivity advantage of small-scale farms (Wegner & Zwart 2011). However, the longer working hours of small-scale farmers actually compromised their welfare in general, which also companied with lower productivity per working hour (Pinzke 2003).

Increased capital intensity through investment in new technology leads to higher fixed costs, but lower average variable cost, so it can reduce production cost per unit by larger scale operations (Kvaløy & Tveterås 2008).

The division of labour based on specialization was detected as interviewees in large-scale farms were more likely to be managers or technicians than owners. However, most full-time employees were hired labourers engaged in general farm work with no clear specialization. In contrast part-time employees were often highly specialized, engaged in activities such as thinning and harvest, transportation team, and system maintenance

5.4.3. Farming system-intensification level

Farm intensification level can affect productivity and annual revenues significantly, this could reflecting on labour used on farms. Improved scientific understanding and technical development have meant that farming systems and processes have become more clearly definable (Muir 2005). In China's official statistics, aquaculture systems have been categorized by the salinity of culture water (freshwater and marine water), type of water body (e.g. pond, lake, reservoir, river or ditch), and culture systems (pond, pen, cage and indoor system), in which freshwater pond culture is the most important farming system, accounting for over 40% of total production in 2011 (MOA 2012). Although pond culture has become intensified over the last decades, pond farming remains comparatively low-tech and limited in terms of intensification potential. Intensive production like high-technological solutions for fish cultivation such as land based fish farms using recycling technologies (Olsen *et al.* 2008). Pond farming systems were believed to be most suited to semi-intensive production using natural productivity and internal recycling of nutrients (Muir 2005), but this study shows they can be highly efficient units for intensification, producing fish and shrimp at prices that are globally competitive. Less intensive farming systems were usually seen as having a lower impact on the environment (New 2003) but this may be simplistic as there are always trade-offs among different environmental impact categories. Industrial aquaculture in developed countries has had to adopt labour-replacing technologies as production and processing systems intensify (Ahmed & Lorica 2002). Although criticisms of intensified aquaculture can be justified, it is more efficient in terms of nutrient use and less polluting of the aquatic environment in terms of unit fish production (Edwards 2011a).

This study shows shrimp farms had higher intensification levels than tilapia farms, especially the high-level shrimp farming system. Shrimp farming had both shorter production cycles and more farming cycles per year than tilapia farms. The land productivity in terms of value was much higher than tilapia, although it was lower in production terms. Shrimp farming consumed more energy than tilapia farms. Although eFCRs of shrimp farming were lower than for tilapia, feed protein levels were higher, requiring LCA to gain a more holistic system perspective of feed efficiency.

This study shows labour requirements for shrimp farming were much higher than for tilapia, mainly because no automatic feeding was used, and that there were significant differences in labour efficiency related to farming systems and their intensification levels. Unlike Thailand shrimp industry highly relies on migrant labour (Humanity United 2013), migrant labour China is strictly controlled, and labour shortage will be a long term issue as discussed in chapter 3, which implies labour productivity will become a priority to develop. It was reported automatic feeding machines have being used in shrimp farming, which can raise labour productivity significantly (Limsuwan & Ching 2013), it was not widely used in China. Shrimp farming has much higher risk and returns than tilapia farming, encouraging or demanding full-time employment and discouraging pluriactivity. Haque *et al.* (2014) found that farm pluriactive mainly correlated with household type and wellbeing, but this study found it mainly related with work load at farm level, which is decided by farming systems and farm species. In contrast automatic feeding has reduced daily labour requirements in tilapia farming leading to the activity being more part-time but also opening up opportunities for contracted specialists within the sector. Intensification level of tilapia farming differed little between systems. The livestock integrated system needs additional labour inputs, but on a household level this makes a lot of economic sense.

Shrimp farming systems spanned a continuum of intensification, with high-level shrimp farms being more intensive than earth pond shrimp monoculture and polyculture farms. Stocking density, survival rate and yields were much higher for high-level shrimp farms which tended to have more, but smaller- sized, easily managed and intensified ponds (He & Sun 2004). High yield, high-level shrimp farms performed better in terms of land and labour productivity than low-level shrimp farms, although at the cost of higher energy consumption.

Reservoir tilapia farms had a lower intensification level, characterised by lower stocking density and lower yield, compared with tilapia pond farms. However, reservoir tilapia farms had better labour productivity and energy efficiency, and similar value output per ha compared to pond farms due to higher farm gate price, as tilapia farmed in large water bodies like reservoir can get better flavour (less off-flavour) (Jia *et al.* 2013).

More intensified cage farming and land based flow-through and recycling aquaculture systems (RAS) have be seen as representing high technological solutions for aquaculture (Olsen *et al.* 2008). Industrialized super-intensive indoor tank shrimp farming systems was introduced into China by the Charoen Pokphand (CP) company through the so called "Turbo Program" (Lin 2012) were not sustained, nor have RAS or cage farming systems become established. The fact that there is no cage system in China is out of sync with Indonesia and Thailand where it is common-although production costs are much higher than Chinese pond system. Another reason is the environmental protection policy kept cage farming out in many water bodies (see Chapter 3). Approaches to further intensify pond-based farming systems for both shrimp and tilapia are urgently required and under development (T. W. Brown et al. 2010). The major limiting factor of super intensive systems are the much higher energy consumption and costs compared with pond farming systems (Che *et al.* 2010). High-value fish and new technologies for farming them, though technically possible are often too costly to be profitable (Neori & Nobre 2012).

5.4.4. Market orientation

CIQ farms only accounted for a small proportion of total farms, but most of them were large-scale farms. A higher proportion of reservoir tilapia farms were CIQ registered than tilapia pond farms; almost no integrated tilapia farms were CIQ registered. CIQ farms were more likely to be leased from local village and managed by salaried labour, and all CIQ farms had trade names.

CIQ shrimp farms had higher land productivity and labour productivity, but lower feed and energy efficiency compared with non-CIQ farms. CIQ tilapia farms performed better according to most productivity and efficiency indicators; only calculated feed efficiency was lower than in non-CIQ farms. The better performance of both shrimp and CIQ tilapia farms was also related to the fact that a high proportion were large-scale farms, and less limited by land and for tilapia especially less energy input in reservoir farms.

5.4.5. Farm location

Tilapia farms in Hainan were quite different to farms in Maoming. Most tilapia farms in Hainan were medium-scale and few were-integrated with livestock. A higher proportion of tilapia farms in Hainan had CIQ registration than in Maoming. Very few tilapia farms in Hainan were owned by farmers, as most of came from another province in China. Farming practice on tilapia farms differed from those in Maoming, although the stocking density was higher, the survival rate and yield were lower, and both reported eFCR and calculated eFCR were higher than that in Maoming. However, because most tilapia farms in Hainan were medium-scale, they performed better on labour productivity in both production and value output terms, and they had better energy efficiency. As with striped catfish farms in some areas in Vietnam (Belton, Little, et al. 2011), tilapia farmers in Hainan had higher levels of professionalisation and ran farm more like businesses.

5.4.6. Follow-up survey

Most farms were found to be either farming as normal with some changes or no significant change, although around 12% shrimp farms and 4% tilapia farms had stopped permanently and fewer temporarily stopped or planned to stop. Disease related factors such as stock losses and poor seed quality were the major reasons causing shrimp farms to stop farming, while diseases and low sales price were the major reasons for tilapia farms.

The most important change was price fluctuation, which during the period under study referred mainly to tilapia price decreases and shrimp price increases. The price changes also reflected tilapia beings more affected by depressed global market conditions related to the economic crisis (Beckman *et al.* 2009), and the rising domestic market demand for shrimp products (CBI 2013b; Cui & Xiao 2013).

Shrimp farming appears to be developing towards further intensification, with higher stocking densities and more lined ponds reported by farmers. However, greater intensification of low technology systems like ponds is relatively risky, as already experienced in shrimp aquaculture (Olsen *et al.* 2008). The high risk of shrimp farming can also explain the higher rate of shrimp farmers who have decided to permanently stop farming.

Under such pressures as low farm gate price and high mortality caused by diseases (Liu, 2011), tilapia farmers reported decreased stocking density and diversification of both their culture systems and their broader livelihood portfolio.

6. Chapter 6 Sustainability perspectives and developing sustainability indicators for farmed tilapia and shrimp value chain in China

6.1. Introduction

Food systems are a set of activities ranging from production to consumption, and by their nature have multiple determinants: environmental, social, political and economic (Ericksen 2008). Sustainable food production was defined as *"successful management of resources and eco-systems to satisfy changing human needs, conserve natural resources and maintain or enhance the quality of the environment"* (Muir 2005).

Aquaculture development decisions have tended to be driven by revenue generation (Schmitt & Brugere 2013). However, sustainability is equally important as profitability and crucial for the sustained management and development of the aquaculture industry (Neori & Nobre 2012). Increasing technological efficiencies in the use of land, water, food, seed and energy is not enough for aquaculture development as broader sustainability involves social and economic issues such as user conflicts (Costa-Pierce *et al.* 2011).

EU legislation has promoted an ecosystem approach to aquaculture and its three objectives: human well-being, ecological well-being, and multi-sectorial integration (Nunes *et al.* 2011). New (2003) defined responsible (sustainable) aquaculture as "*profitable aquaculture with a conscience*", which embodied economic and social perspective of aquaculture. Conserving the environment versus the exploitation of natural resources for food production is an important question for stakeholders (Bostock *et al.* 2010). Aquaculture must become less short-term and less production oriented, more ecologically, community, and culturally based, and needs to evolve in an environmentally friendly and socially responsible way (Costa-Pierce 2007). Local decision making, human capacity development, and collective action to generate productive aquaculture systems that fit into societal constraints and demands need to be emphasized (Diana *et al.* 2013). In marine aquaculture, private sector business needs to integrate with ecosystem ideas to achieve both ecological sustainability and economic success (Naylor & Burke 2005).

Aquaculture must deal with environmental regulations, management difficulties and resource and social conflicts in the crowded twenty-first century (Costa-Pierce 2007). It requires an interdisciplinary approach and will need research based on an entire farming system; thus, there has to be a paradigm shift in research strategies from a commodity-centred approach to an integrated natural resources management procedure covering the entire cropping system (Swaminathan 2006), and shift in understanding the relationship between humanity and the environment, from only promoting economic growth to combine with social development and environmental protection (Mampan *et al.* 2011).

Sustainability of production and trade is also likely to be impacted by the relative efficiency of farmed seafood production compared to other food production systems, in terms of profitability, resource use and their environmental impacts. Sustainability includes economic considerations such as: will I make a profit? Will I be able to bequeath my farm to my children, and, at a subsistence level, will I and my family be able to eat tomorrow? (New 2003). Local perceptions of sustainability, by producers and other value chain actors, however, are essential to understand likely development trajectories. There is little research on stakeholders' perceptions of the aquaculture industry (Chu *et al.* 2010; Mazur & Curtis 2008; Nash 2004).

Empirical research from around the world shows the benefits of engaging local communities in sustainability monitoring (Reed *et al.* 2006), and community development (Mampan *et al.* 2011). Participatory approaches have been widely used in the development literature, and it is often portrayed as the solution to all ills without any acknowledgement of the difficulties that it poses in practice (Bell & Morse 2008). The unpacking of ideas relating to participation, learning and thinking in different ways requires that local people have clear ideas of their own about what is sustainability (from their own perspective and in their own terms) without an expert's view (Bell & Morse 2008).

Participatory approaches have been wildly used in agricultural research and technology extension among small-scale farmers (Martin & Sherington 1997; Douthwaite *et al.* 2002; World Bank 1996; Nhan *et al.* 2005). The Participatory Rural Appraisal has been adopted in aquaculture research projects, using secondary data, key informant interviews, triangulations and statistical analysis of analysis development status and trends (Barman *et al.* 2002; Edwards *et al.* 2002). Stakeholder analysis and workshops can be used in to understand multi-perspectives and in conflict situation (Edwards *et al.* 2002). It is increasingly realized that sustainable development and responsible production of aquaculture, in the long run, cannot be achieved without the full participation of the producers in the decision-making and regulatory process, which has led to efforts to empower farmers and their associations and move toward increasing self-regulation (Subasinghe *et al.* 2009).

However, according to Reed *et al.* (2006) participatory approaches also have their failings, such as indicators developed with participatory approaches that do not have the capacity to accurately or reliably monitor sustainability. In order to measure sustainability and develop sustainability indicators, Reed *et al.* (2006) proposed a learning process that integrates best practice for stakeholder-led local sustainability assessments. By integrating approaches from two different paradigms, expert-led (top–down) or community-based (bottom–up), the proposed process offers a holistic approach for measuring progress towards sustainable development. It emphasizes the importance of participatory approaches setting the context for sustainability assessment at local scales, but stresses the role of expert-led methods in triangulation and dissemination.

The evaluation of sustainability is a participatory process requiring an evaluation team with an interdisciplinary perspective, the evaluation team should include external evaluators and internal participants (farmers, technicians, community representatives, and others involved) (López-Ridaura *et al.* 2002).

Sustainability measurement frameworks have been developed, such as the Differential Drivers–Pressure–State–Impact–Response (DPSIR) methodological approach, used to compare ecological and economic performance between different farming systems (Nobre *et al.* 2010), and the Sustainable Livelihoods framework developed for exploring and explaining sustainability issues, particularly in a rural development context (Carney 2003; Muir 2005).

The DPSIR framework generally reflects a systems analysis view of the relations between environmental and human systems, and social and economic developments exerting Pressure on the environment and, as a consequence, the State of the environment changes, such as the provision of adequate conditions for health, resource availability and biodiversity. Finally, this leads to Impacts on human health, ecosystems and materials that may elicit a societal Response that feeds back on the Driving forces, or on the state or impacts directly, through adaptation or curative action (Smeets & Weterings 1999).

Besides sustainable perceptions and factors, sustainability indicators (SIs) became a means of gauging sustainability (Bell & Morse 2008), and have been widely employed in many studies (Gallego Carrera & Mack 2010; Gibbs 2007; Hezri & Dovers 2006; López-Ridaura *et al.* 2002; Reed *et al.* 2006; Singh *et al.* 2007; Tisdell 1996; Wallis *et al.* 2010). It was believed that SIs are "*bits of information that highlight what is happening in a larger system. They are small windows that together provide a glimpse of the 'big picture'"*(Keniry 2003), and *"An indicator is something that helps you understand where you are, which way you are going and how far you are from where you want to be"* (American Forests 2003). Using SIs should not just gather all information but rather selectively use all SIs, which are more fundamental in essence and more likely to produce the most accurate information about the status of practice (Shen *et al.* 2011). SIs have to be accurate, objective, easy to understand and use, be limited in number, and scientifically sound (Kawakami *et al.* 2013). Harger & Meyer (1996) proposed that sound SIs require fulfil certain criteria, such as simplicity, scope, quantification, assessment, sensitivity, and timeliness (Harger & Meyer 1996). This was developed as the SMART criteria (Specific, Measurable, Achievable (or Attainable and aggressive), Relevant (or Realistic), and Time-related) (Kawakami *et al.* 2013; Shahin & Mahbod 2007).

The purpose of this study was to prioritise the leading stakeholder-led local sustainability factors and potential sustainability indicators of value chains of tilapias and shrimps in China. Systems thinking and interdisciplinary methodologies in which both top–down and bottom–up approaches were combined and participatory approaches were used to understand the context for sustainability assessment at local scales, using triangulation methods to compare results with different stakeholders to improve the generalizability of results.

6.2. Methodology

This section included two steps: the first step was shrimp and tilapia farm level baseline survey; and the second step was State of System (SoS) workshop.

6.2.1. Farm survey

Farm survey methods were presented in Chapter 5. Farmer's children's future, sustainability perspectives and development trends were asked as open questions in the survey, the questions related to this chapter were listed in Table 6.1.

Table 6.1 Survey questions

Categories	Questions
Children's future	Would you like your children to farm shrimp/ fish in the future?
	Give reasons for your answer re. children future in shrimp/ fish farming - whether yes or no
Development trends	The main changes in landholding & use patterns over the last five years?
	The main changes in visited farm infrastructure over the last five years?
	The main changes in aquaculture production patterns over the last five years?
	The main changes in labour patterns over the last five years?
	The main changes in feed management over the last five years?
	The main changes in water management over the last five years?
	The main changes in chemical and substance use/management over the last five years?
Sustainability perceptions	What are the factors that will positively or negatively affect your farm the next one to two years?
	Specified factor positive, negative or uncertain
	Rank all the identified sustainability factors
	What do you plan to do about it?

6.2.2. State of the System (SoS) workshop

The State of the System (SoS) workshop was conducted to review and summarise the outcomes of systems analyses conducted during the scoping and baseline survey. The workshop was held in Zhanjiang, Guangdong, China, in April, 2011. Forty one stakeholders were present at the workshop comprising six stakeholder groups including which were feed and chemical suppliers (n = 9), shrimp farmers (n = 8), processors (n = 1), extension &regulation (n = 5), hatcheries (n = 7) and tilapia farmers (n = 5). Six journalists also joined the workshop but only as observers.

Two exercises were conducted to identify sustainability factors and indicators by all participants. For the first exercise, all participants were asked the following question, previously asked of farmers in the integrated farmer survey: “What factors do you foresee that could POSITIVELY or NEGATIVELY affect the performance of your business or service over the next 1-2 years?” To avoid biasing individual opinion, this exercise was conducted immediately after participant registration.

The results were immediately coded and entered into a pre-prepared relational ACCESS database, and then ranked according to citation frequency and rank of factors identified in this exercise. Up to five factors per stakeholder group were selected. Selected sustainability factors were then used by different stakeholder groups in the second exercise. In the second exercise, these factors were listed on the left hand of a flip chart with space to write corresponding responses. Each group was then tasked to: “Identify approaches to measure any change, qualitatively or quantitatively, in each factor over time”. All the responses were recorded as the start point to identify sustainability indicators.

6.2.3. Data management and analysis

Data management and analysis methods for baseline survey data were inherited from chapter 5.

SoS workshop data were entered into the Access database by using suitable tables designed in advance and then recoded to avoid repetition. Responses from the first exercise were presented as sustainable factors by negative and positive classification. Responses from the second exercise were classified and evaluated to form sustainability indicators (SIs). The SIs candidates were classified by the three sustainability pillars (Economic, Social, and Environmental) (Lehtonen 2004), and level of scope and breath (farm level, supply chain level, market level, government level and macro level). Then these SIs candidates were evaluated with the SMART criteria (Specific, Measurable, Achievable, Relevant, and Time-related) (Shahin & Mahbod 2007; Kawakami *et al.* 2013). Scores were given to all SIs ranged from zero to five, based on how they can fulfil SMART criteria (e.g. fulfil Measurable is one score). All qualified SIs need to be five scored.

6.3. Results

6.3.1. Farming –the next generation

The answer given by farmers for the question "Would you like your children to farm shrimp/fish in the future?" was mainly "no"; the response of 81% shrimp farmers and 86.5% tilapia farmers. Only 16.5% shrimp farmers and 11.6% tilapia farmer responded positively, all others were don't know or unsure (Figure 6.1). Chi-square test shows no difference between shrimp and tilapia farmers, or between different farming system, farm scale, farm location or CIQ registration (P>0.05).

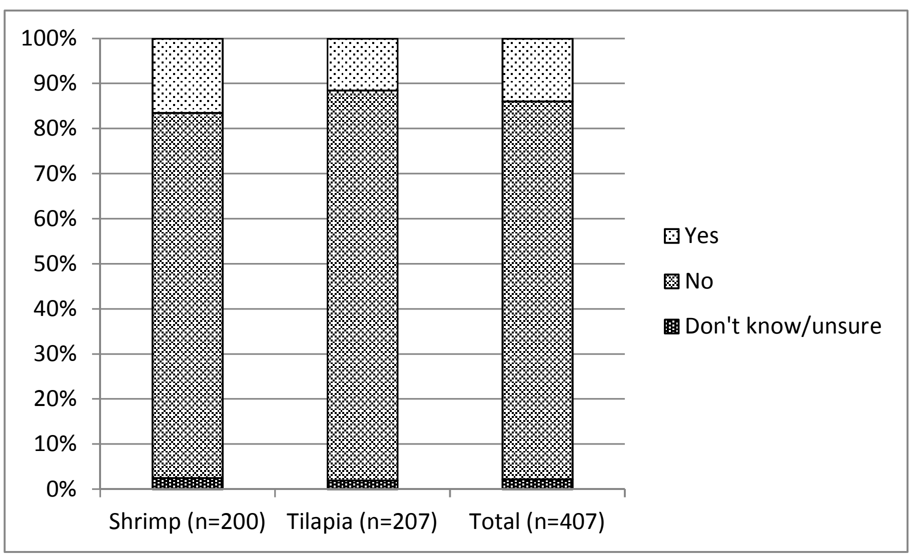


Figure 6.1 Proportion of farmers' preference for their children's future

The reasons given by farmers for the answer was divided according to their willingness "yes" and "no" (Figure 6.2). "Hard work", "High risk" and "Poor economic income" were the top three reasons for the answer "no". "Good economic income" and "Continuation of the family business" were the only two reasons for the answer "yes". Chi-square test showed no difference between shrimp and tilapia farmers, or between different farming system, farm scale, farm location or CIQ registration (P>0.05).

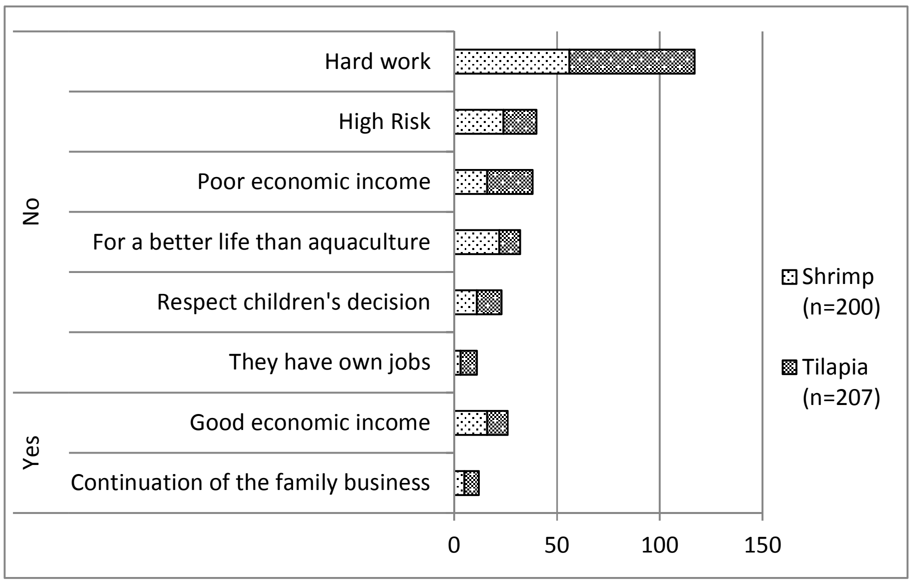


Figure 6.2 Reasons given by farmers for the preference of their children's future

6.3.2. Main development trends identified by farmers

For the open questions about farm development trends, 176 records of development trends were identified by farmers that could be coded as changes to: infrastructure (n = 44), labour (n = 35), land uses (n = 27), chemical use (n = 27), water management (n = 23), production (n = 19), and feed (n = 1). However, less than 12% farmers reported changes in each category (Figure 6.3).

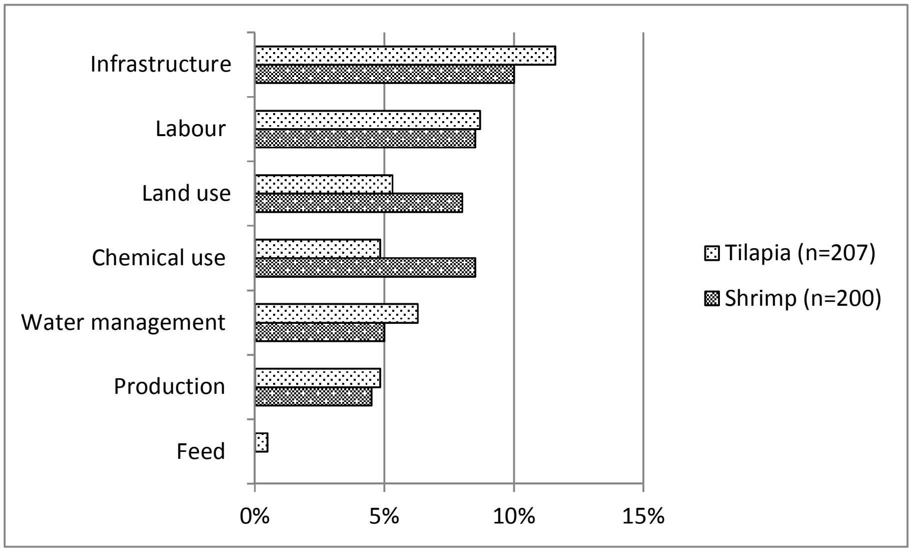


Figure 6.3 Proportion of famers who reported changes in development trend categories

Chi-square test showed that 16% large tilapia farms had farm area changes (either bigger or smaller), which is higher than medium farms 3.9% and small farms 3.8% (P<0.05). Nearly 21% (20.6%) of low-level shrimp polyculture farms reported changes in land area, which is higher than reported by high-level shrimp farms (7%) and low-level shrimp monoculture farms (3%) (P<0.01).

More low-level shrimp polyculture farms had production changes (14.7%) than high-level shrimp farms (2%) and low-level shrimp monoculture farms (3%) (P<0.01). Large-scale shrimp farms also had more production changes (12.9%) than medium (0%) and small-scale farms (5.3%) (P<0.05).

High-level shrimp farms had more labour changes (14%) than low-level shrimp monoculture farms (1.5%) or low-level shrimp polyculture farms (5.9%) (P<0.05). Reservoir tilapia farms also had more labour changes (40%) than tilapia pond farms (9.6%) and integrated tilapia farms (4.9%) (P<0.01). Large-scale shrimp farms had more labour changes (25.8%) than medium (9.5%) and small (2.1%) farms, large-scale tilapia farms also had more labour changes (36%) than medium (9.1%) and small (1.9%) farms (P<0.01). CIQ shrimp farms had more labour changes (33.3%) than non-CIQ farms (5.6) (P<0.01), and CIQ tilapia farms also had more labour changes (24%) than non-CIQ farms (6.6%)

(P<0.05).

More large shrimp farms had water management changes (16.1%) than medium (4.1%) and small farms (2.1%) (P<0.01), and more CIQ shrimp farms had water management changes (19%) than non-CIQ farms (3.4%) (P<0.01).

The most important land use change trend identified by tilapia farmers was expansion of farm area, followed by increases in pond rental and change of ownership of farms. The most important land use change trends identified by shrimp farmers was increased pond rentals, followed by declines in pond rentals, change of ownership of farms, expansion in farm areas, and reduction in farm area. However, in the context of the overall sample size these changes were uncommon (Figure 6.4), and no statistic was performed due to limited responses.

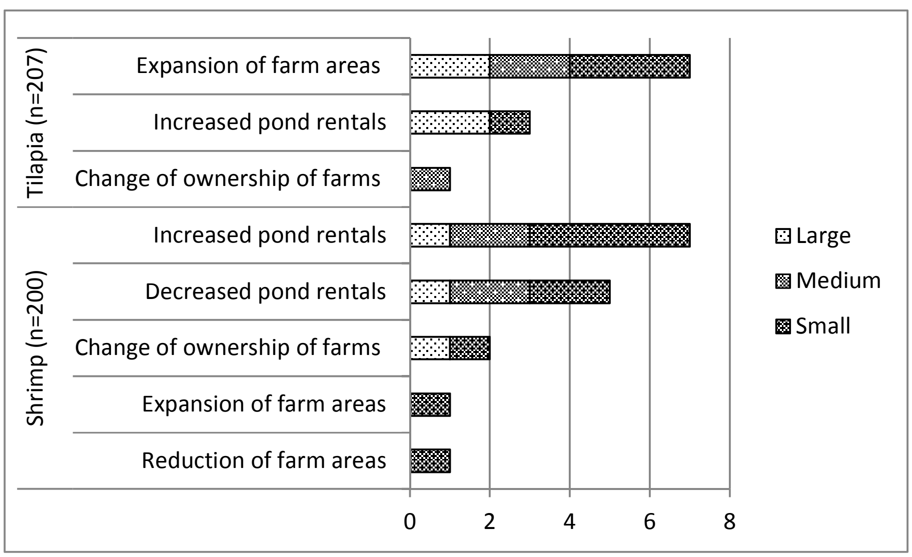


Figure 6.4 Number of farmers reported land use changes by different scales and species

The most important trends identified of infrastructure change were the deepening and enlarging of ponds by tilapia farmers and the lining of shrimp ponds (Figure 6.5). More new equipment was the second change for both shrimp and tilapia, which included wells, feeding machines, aerators and fishing boats. Pond renovation was the third trend for both tilapia and shrimp farms.

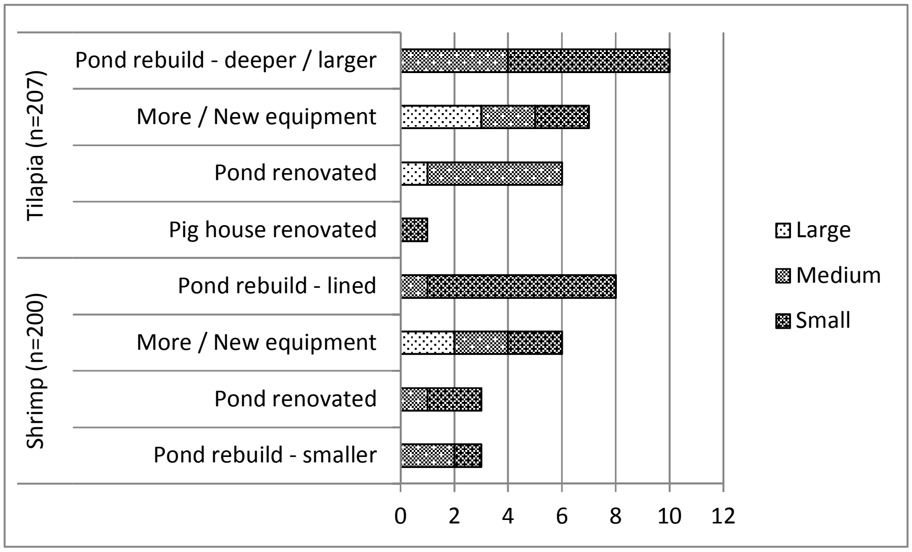


Figure 6.5 Number of farmers reported infrastructure changes by different scales and species

There were no clear production changes for tilapia, with some diversified changes reported by farmers (Figure 6.6). The main trends of shrimp farms were changing from monoculture to polyculture and farming species changed from tilapia to shrimp. Those shrimp farms that changed from monoculture to polyculture were mainly low-level shrimp farms.

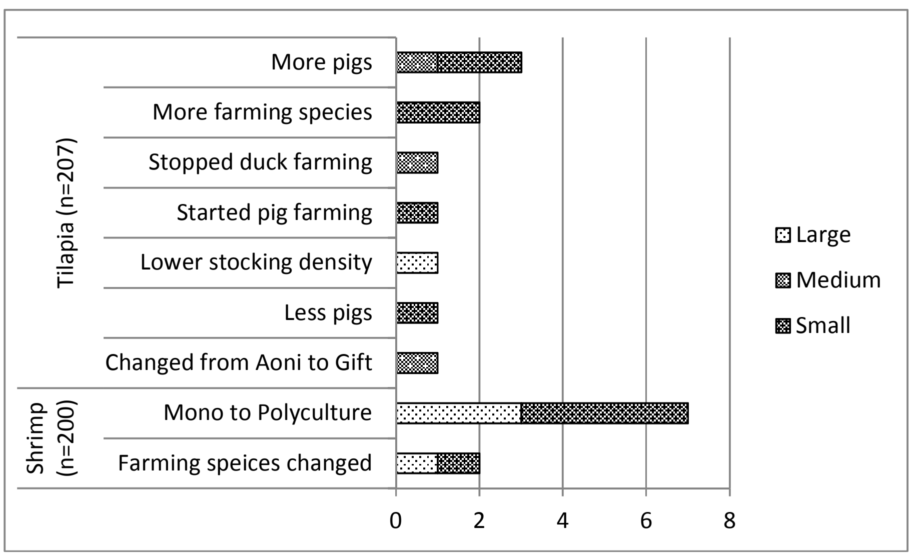


Figure 6.6 Number of farmers reporting production changes by different scales and species

For both tilapia and shrimp, the most important labour-related trend was increased wages. More worker mobility and labour shortages were second and third important issues for shrimp and tilapia, in line with general trends nationally and especially in the coastal provinces (Wegner & Zwart 2011) (Figure 6.7).

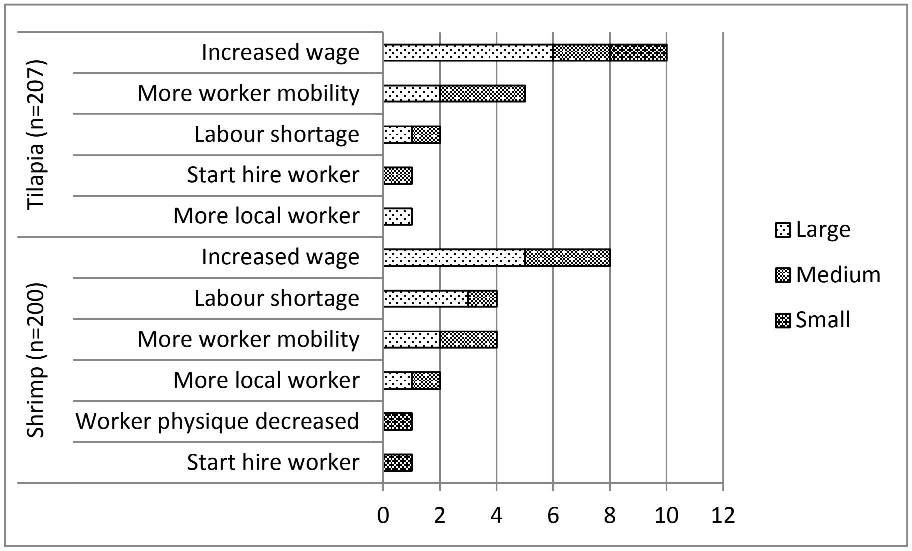


Figure 6.7 Number of farmers reporting labour changes by different scales and species

More water treatment was the major water management trends for both shrimp and tilapia farms, followed by worse water quality and water shortage (Figure 6.8). The major water treatment included using probiotics and other water treatment chemicals. All three tilapia farms that reported water shortage were in Hainan.

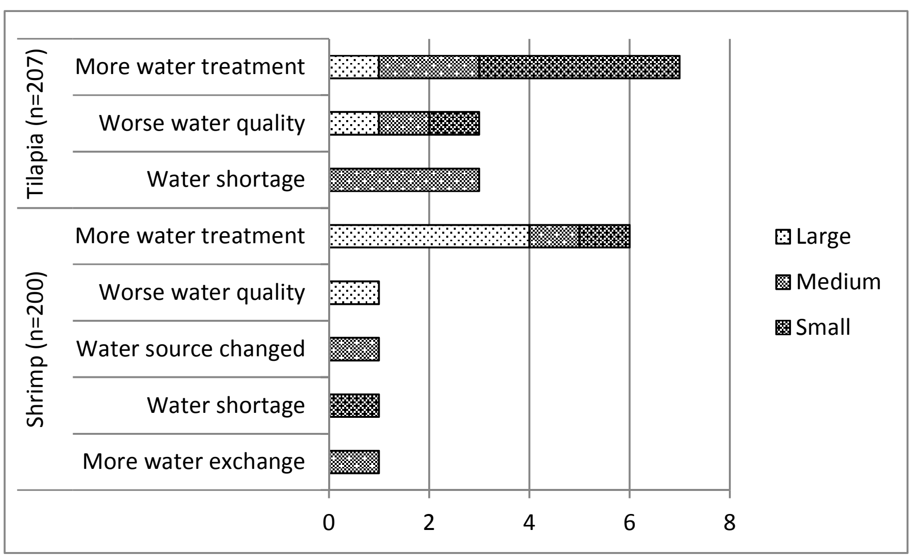


Figure 6.8 Number of farmers reporting water management changes by different scales and species

The only feed use change was the change from commercial feed to farm made feed by a medium-scale CIQ tilapia farm in Maoming.

6.3.3. Main sustainability factors identified by farmers

A total 1102 sustainability factors were identified by farmers, 94% (n = 1036) of which were negative factors and only 6% (n = 66) were positive factors.

Weather was the most important negative factor for both shrimp and tilapia farms, reported by more than 85% shrimp farmers and 64% tilapia farmers, which included weather changes and extreme weather. Water quality and disease were ranked second or third for shrimp and tilapia farms, as water quality degradation was often related to disease (Svobodová *et al.* 1993). Seed quality was the fourth important factor for shrimp, which was reported by more than 37% of shrimp farmers compared to only 13% tilapia farmer. More than 20% (23%) of shrimp farmers reported chemical contamination, which was also much higher than reported by tilapia farmers (4%). Sixteen per cent of shrimp farmers reported high stocking density as a negative factor, which is mainly due to the association between high density farming practice and high disease frequency (Cui & Xiao 2013). Sixteen per cent of tilapia farmers reported low profit as a negative factor, while only 5% shrimp farmers reported that, which mainly caused by different farm gate price between shrimp and tilapia. Other negative factors included feed quality, high capital and credit costs and others, such as feed cost and water availability (Figure 6.9).

Chi-square test showed 23.8% CIQ shrimp farms reported feed quality as a negative factor, which is higher than non-CIQ shrimp farms (6.7%) ($P<0.01$). More farms in Maoming (20%) reported low profit as a negative factor, which was higher than farms in Hainan (8.3%) ($P<0.05$). Nearly 20%

(19.3%) of farms in Maoming reported seed quality as a negative factor, which was higher than Hainan (4.2%) (P<0.01). No reservoir farms reported water quality as a negative factor, whereas around a quarter of tilapia pond farms (23.4%) and integrated farms did (28.8%) (P<0.01). More farms in Maoming (34.8%) reported water quality as a negative factor, which was higher than Hainan (20.8%) (P<0.05).

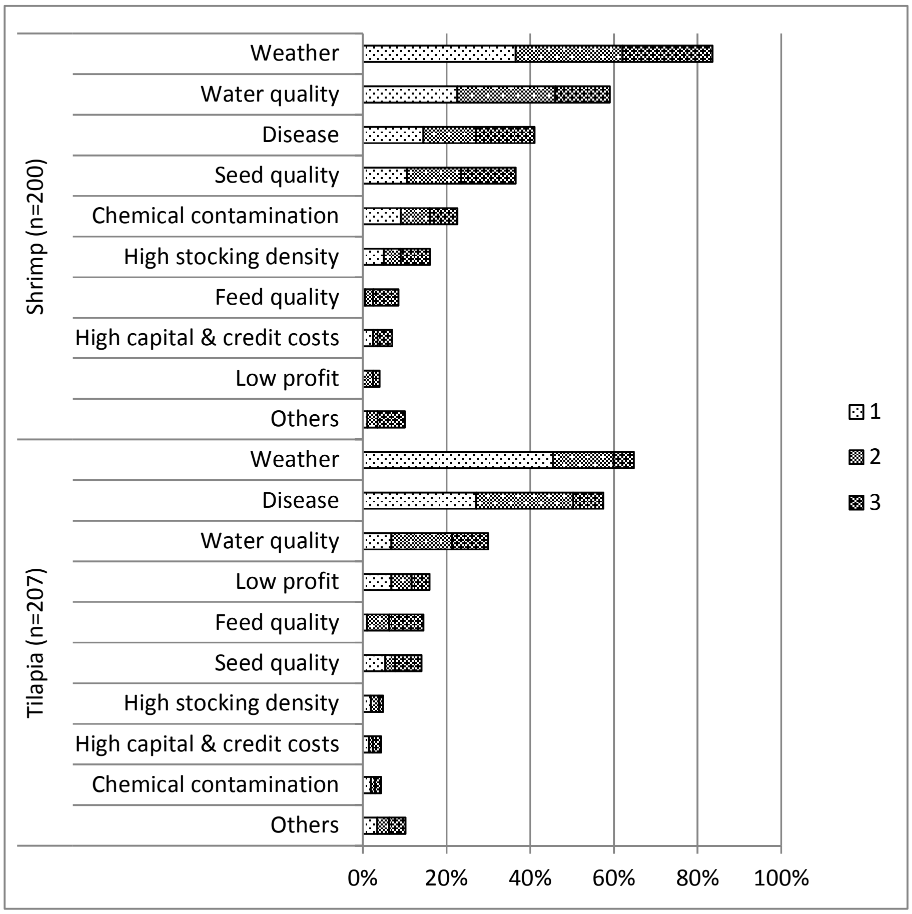


Figure 6.9 Proportion of farmers reporting negative sustainability factors by ranks and species

Fewer positive factors were reported, and by far fewer farmers (4%) (Figure 6.10). Farm expansion and good weather were the most important positive factors for shrimp farms, while water quality was the most important factor for tilapia farms. Two per cent of hrimp farms reported high yield and farm location were also important, while around 2% tilapia farms reported high market demand and good weather as important. Most other positive factors were highly diverse and showed no clear trends. Due to the low number or positive factors, no statistical analysis was employed.

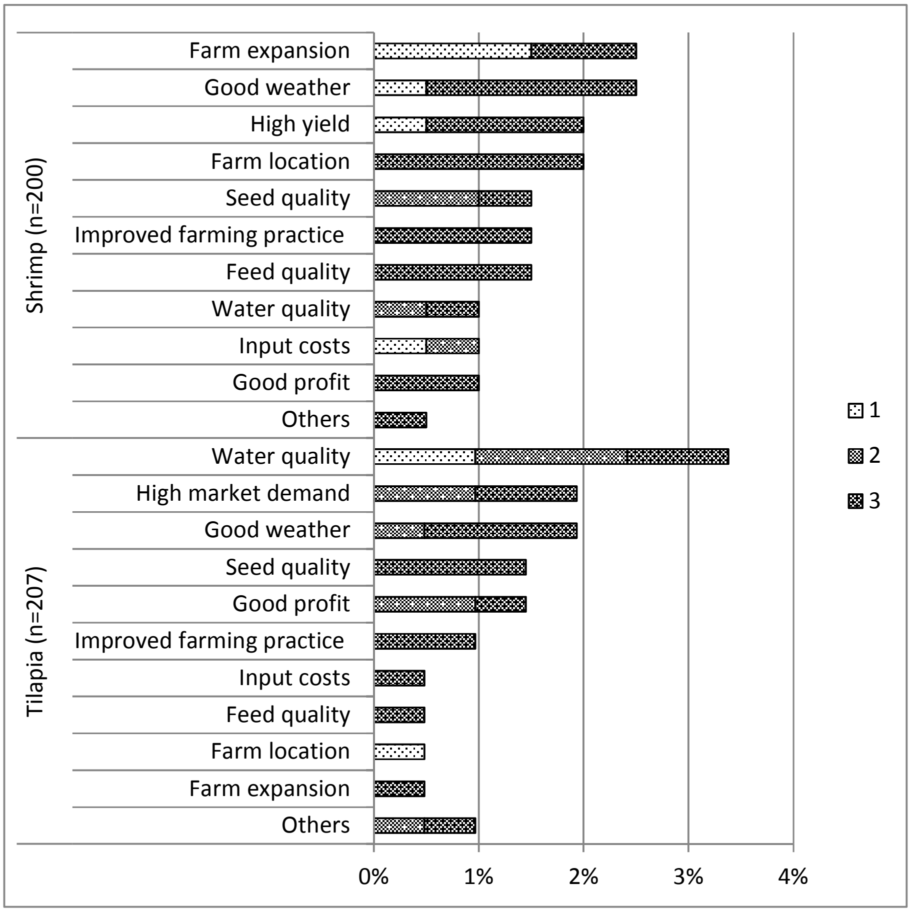


Figure 6.10 Proportion of farmers reporting positive sustainability factors by ranks and species

6.3.4. Farmers proposed responses to negative sustainability factors

Improve techniques and practices were the most important responses to negative factors proposed by both shrimp and tilapia farmers, followed by changing seed source/species/inputs, more aeration and more disinfection by shrimp farmers and more use of disinfections and pharmaceuticals, and greater water exchange by tilapia farmers (Figure 6.11). Other proposed responses included reducing farming area, increased water exchange. Shrimp farmers suggested more support from the authorities, and more aeration. Tilapia farmer identified collective action and more support from the authorities as suitable responses. Due to low number or proposed responses, no statistical analysis was employed.

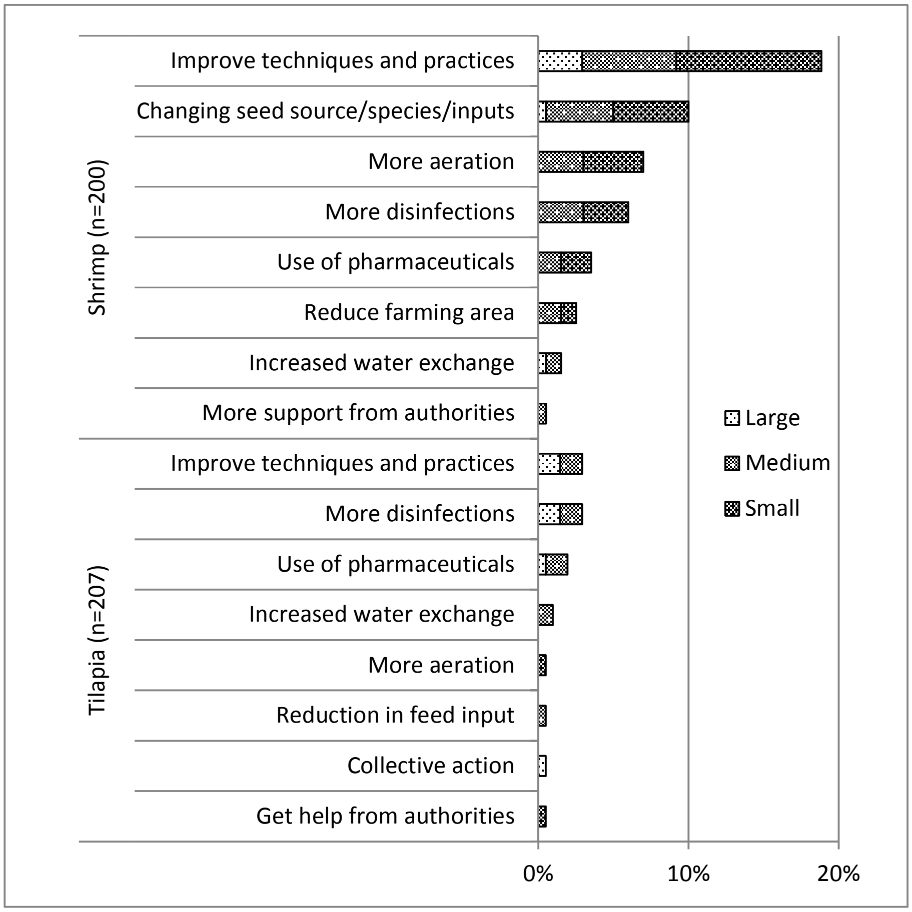


Figure 6.11 Proportion of farmers reporting responses to the negative sustainability factors by farm scales and species

6.3.5. Key sustainability factors identified by the whole value chains

One hundred and seventy four sustainability factors were identified by stakeholders in the SOS workshop, and then were classified as either positive or negative.

The top six important negative sustainability factors were disease, seed quality, water availability & quality, high input costs, feed quality and weather, which was similar to negative sustainability factors identified by farmers in the baseline survey. Other negative factors included vary aspects of farming practice (Figure 6.12).

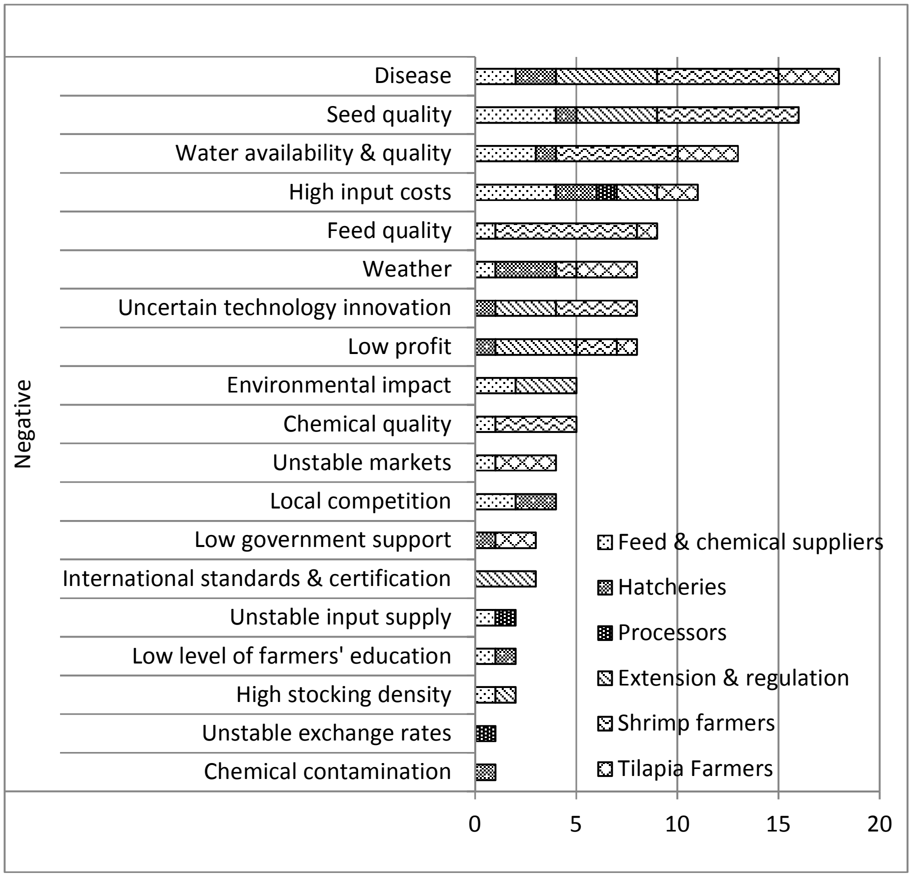


Figure 6.12 Number of records of negative sustainability factors identified by different value chain stakeholders

The top six important positive sustainability factors were innovation in production technology, market demand, seed quality improvement, government intervention, high profit and more marketing. Those major positive factors were neither the same, nor similar to the positive factors collected in the baseline survey, and had a broader perspective than those identified at farm level, such as market demand, government intervention and marketing. Other positive factors were presented in Figure 6.13.

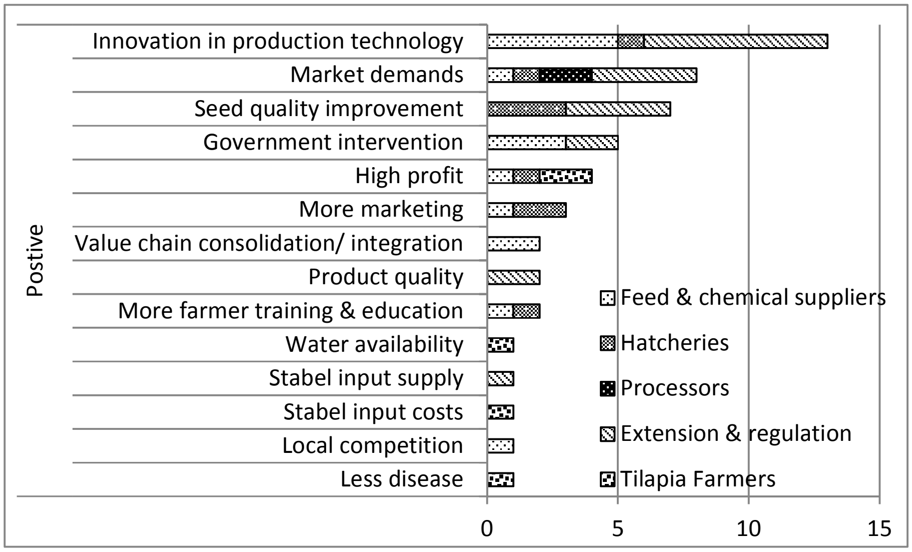


Figure 6.13 Number of records of positive sustainability factors identified by different value chain stakeholders

6.3.6. Development of sustainability indicators (SIs)

Ninety nine SIs were identified, 67 in the economic category, followed by 23 social and nine environmental. The unbalanced SIs among different sustainability pillars revealed the value orientation of stakeholders. In the economic category, farm and supply chain levels had most SIs, followed by macro level SIs. In the social category, macro level government levels accounted for most SIs. In the environmental category, macro and farm levels had similar numbers of SIs. These SIs were also distributed among different categories and levels (Figure 6.14).

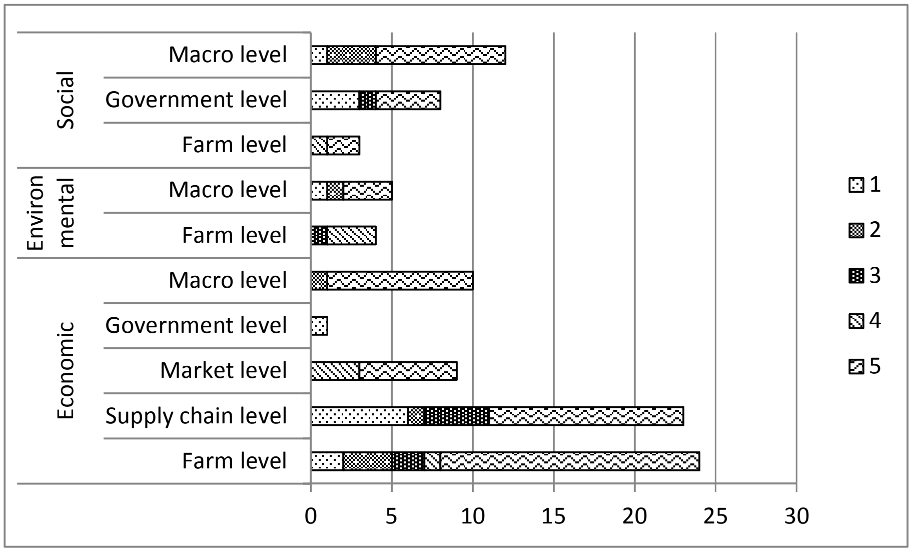


Figure 6.14 Number of stakeholder identifying sustainability indicators, classified social, economic and environmental, and scores according to the SMART criteria (specific, measurable, achievable, relevant, and time-related)

Among all SIs, 60 scored five according to the SMART criteria (Appendix 4). Among 60 five scored SIs, 33 were State (S) SIs, followed by 12 response (R), nine impact (I), four pressure (P), and two driving forces (D). The economic category had most SIs, followed by social and environmental. State SIs were mainly economic, and some in the social at the macro level (Figure 6.15). The uneven distribution of SIs in different categories and levels requires better balance before application.

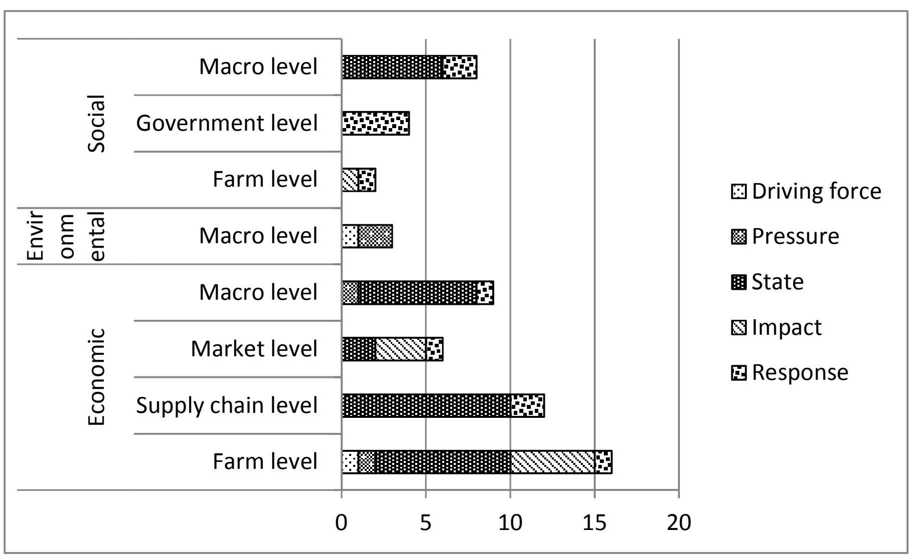


Figure 6.15 Number of five scored sustainability indicators and divided by the DPSIR (driving force, pressure, state, impact and response) framework.

6.4. Discussions and conclusions

6.4.1. Farming –the next generation

One important and practical sustainability indicator for agriculture is that the children of current farmers continue farming, as sufficient farmers are needed to maintain farming activities (New 2003). However, farmers often state that they do not want their children to become farmers because of the relatively low standard of living it provides on resource-poor small-scale farms (Edwards 2010; Rigg 2003). This study found the same result, and more than 80% farmers don't want their children to continue basing their living on aquaculture. The main reasons given by farmers were the hard work, high risk and low income associated with aquaculture. These reasons were also related to the status of most farmers were small-scale and low labour productivity found in chapter 5. Comparing with maintaining a large farmer population, increasing in *per capita* productivity can provide same amount food and liberate the unnecessary labour force.

Industrialisation and urbanisation offered more opportunities for farmers to access non-agricultural employment and move to other sectors (Kuznets *et al.* 1941). Along with economic development, sufficient job opportunities were created, and labour shortages and rising labour costs have gone from being a seasonal issue mainly in South China to becoming a more nationwide problem throughout the year (Wang *et al.* 2012). Off farm employment has become the primary income source for rural residents rather than agriculture in many contexts (Huang *et al.* 2012). Urbanisation and off-farm jobs tend to provide much higher living standards than traditional agriculture can provide (Chambers & Conway 1992). Farmers' choices were reasonable and feasible in the context of a fast growth economy and plentiful off-farm job opportunities. The result of labour changes in development trends sections also confirmed the wage increased and labour shortage in the last few years.

On the other hand, requiring farmers' children to continue to make a living in agriculture or aquaculture farms is morally wrong, as all humankind are equal and free to choose their own life, despite what their parents did. Although few farmers responded positively and provided reasons, such as good economic income and successful family business, their children may still have their own ideas. Nonetheless, farmers' opinions about their children reflected their perspectives of their own lives. Their unwillingness for their children to make a living from aquaculture reveals their dissatisfaction with their involvement in aquaculture, raising questions about the questionable sustainability of aquaculture in China from a social perspective.

6.4.2. Main development trends

Only a small proportion of farms reported changes in the five years prior to the survey, which reflecting the comparative stability of the sector. The stable status of the aquaculture industry is in part of a consequence of the country's stable economy, and slow progress of land consolidation which is limited by current land policy (Wang *et al.* 2012). Land use changes in tilapia farms were mainly in terms of expansion in farm area and increases in pond rent. However, shrimp farmers reported contradictory trends, with some pond rents increasing and some decreasing. Fluctuations in shrimp pond rental are primarily a result of the high risk, high profit nature of shrimp farming (Ye 2011; Wu 2013). Moreover, although aquaculture industry is changing towards higher level of intensification and diversification at macro level, at farm level the farming practice changes is limited by farmers information and knowledge as well as market demands.

Infrastructure change accounted for the highest number of changes in all categories. Rebuilding of tilapia ponds to be deeper and larger is a good way to increase yield (Wang 2000). Infrastructure changes in shrimp farms were mainly ponds were lined, and some became smaller, all were evidence of shrimp farming became more intensified (He & Mo 1998).

The major change in water management was more water treatment, which may be a response to water quality deterioration and high disease risk of both shrimp and tilapia farming (Xian & Zheng 2012; Li 2010).

6.4.3. Sustainability factors

A very large range of different sustainability factors was identified by shrimp and tilapia farmers in the baseline survey and by stakeholders in the SoS workshop, which illustrated variability in concordance in the opinion of their relative importance between stakeholder groups (Table 6.2).

Cost and profit were the major economic sustainability factors, as the nature of aquaculture farmers is more like business owners, instead of traditional subsistence farmers (Wharton 1969). The constraints of low price, low margin and price fluctuation were reported by both farmers and processor plant, especially tilapia farmers, some farmers even losing money from the low farm gate prices in 2009 (Chu *et al.* 2010). The constraint of cost increases mainly caused by price of feed material increasing (feed represents an estimated 70% of production cost) set off a chain reaction of price increasing along the value chain. Shrimp farmers were less sensitive to input costs than tilapia farmers, due to the high farm gate shrimp price (Gao & Wu 2012).

Weather and water availability & quality were the major environmental sustainability factors. Weather changes and extreme weather have great effect on aquaculture farms, as illustrated by huge losses of tilapia during the cold spell in 2008 (Cai & Liufu 2008) and high shrimp mortality caused by extreme heavy rains and typhoon (Wu 2012; Wu 2012), farmers are very vulnerable to such weather extremes. Although overwintering measures such as hapas-in-ponds have proven useful in reducing the risk and improving the survival of tilapia broodstock and fry in the cold season (Dan & Little 2000a; Dan & Little 2000b), large-scale application in grow-out pond systems needs high investment. The present study shows that shrimp farmer were more able to invest in farm infrastructure, such as lined pond or greenhouse, but no tilapia farmers was found doing so due to limited economic incentives. Water quality was seen as one of key factors affecting shrimp and tilapia farming (Li 2010; Xian & Zheng 2012).

Table 6.2 Summary of major sustainability factors identified by different stakeholders in the baseline survey and the SoS workshop.

Category	Sustainability factors	Shrimp farmers	Tilapia Farmers	Input suppliers	Hatcheries	Processors	Extension& regulation
Economic	Input costs		√	√	√	√	√
	Profit	√	√	√	√		√
Environ-mental	Water availability & quality	√	√	√	√		
	Weather	√	√	√	√		
Social	Market demands	√		√	√	√	√
	Government intervention			√			√
Technical	Disease	√	√	√	√		√
	Seed quality	√	√	√	√		√
	Feed quality	√	√	√			
	Chemical quality	√		√			
	Innovation in production technology	√	√	√	√		√

Note: √ means the sustainability factor was identified by this particular group of stakeholders

Social sustainability factors mainly included market demand and government intervention. Market demand for shrimp and tilapia products came from both domestic and export markets (see Chapter 4). Government intervention was raised by input supplier and government officers with potential measures including government support for low farm gate price, government policy support, government effective regulation & coordination, and traceability implementation. It has been argued that the government could help raise tilapia export prices by allocating export quotas and promoting value chain consolidation (Chu *et al.* 2010), or by setting a minimum protective price (Lei *et al.* 2013). Food safety governance and building the traceability system of farmed seafood also requires government to make relevant legislation and regulation and to promote it throughout the value chain (Huang *et al.* 2011; Schembri *et al.* 2007; Zhang *et al.* 2011). Moreover, government also can help farmers to organize farmer club to raise their income (Gao & Wu 2012). However, self-organised shrimp farmer clubs in Thailand did not really want to engage with government as it was seen as a hindrance (Douglas Waley 2014 *per comm*). Despite earlier studies showing government interventions and productivity growth were not correlated (Lee 1996), the value of government interventions continues to be debated and linked to political positions regime choices (Chen *et al.* 2011; Hermes & Lensink 2013; Przeworski & Limongi 1993).

Disease was identified as one of the most important issues across the range of stakeholders and species. Many diseases are linked to environmental deterioration and stress associated with farm intensification (Shang *et al.* 1998). Viral pathogens appear to exert the most significant constraints on the growth and survival of crustaceans under culture conditions (Stentiford *et al.* 2012). Diseases problems of shrimp farming were severe in the last few years, especially the early mortality syndrome (EMS) caused great losses (Flegel 2012; Lv & Lai 2012; Zhang *et al.* 2012; Wu

2012). Tilapia farming also suffered increased disease outbreaks, especially the *Streptococcus* diseases (Hanson *et al.* 2010; Ye *et al.* 2011), *Aeromonas* spp. infectious diseases (Huang *et al.* 2012; Li & Cai 2011), and *Edwardsiella* disease (Zheng *et al.* 2009).

Besides diseases, inconsistent quality of seed, feeds and pharmaceuticals was also identified as a major cross cutting issue. *L. vannamei* broodstock supply still largely relies on imported sources and it was reported that 80% of seed stocked in Zhanjiang area was produced from imported broodstock in 2013 (Cai & Lin 2013). However, along with high demand for imported broodstock, the industry had to accept the highly variable quality of imported broodstock from a major provider SIS company, which inevitably affect seed quality (Ze 2013). At the same time, there is a lack of good local varieties or successful broodstock selection programs in China, which causes much uncertainty about the future of shrimp farming (Cai & Lin 2013). Although tilapia broodstock selection programmes have achieved great success in China (see Chapter 4), cheaper but inconsistence quality tilapia seed produced in so-called “family workshops” or backyard hatcheries still supply up to 60-65% of market share, some sold as fakes of branded seed (Aquaculture Frontier 2010a). The imbalance in information and levels of technology between hatcheries/seed dealers and farmers gave farmers no choice but to accept.

Feed quality and chemical quality were also identified as major sustainability factors, although less important than seed quality. Most farmers were using industrialized pelleted feed (Chapter 5), which the quality of which can be largely guaranteed compared to farm made moist feeds. Farmers’ perceptions of feed quality was mainly related to protein level or fishmeal content, which was not exactly correct; high protein level or high fishmeal content feed is not a guarantee of low FCR or high economic returns (Ye & Cai 2011). More detailed cost-benefit analyses are needed to maximise returns from feed input. At the same time, increasing feed raw material prices, especially of fishmeal, caused great cost pressure on feed companies, and it was believed that lower protein feed must be developed to reduce feed cost (Ye 2013). In such circumstances, different feed quality such as different protein level of different brands is more of a market differentiation strategy than an attempt to address problems of quality. It was widely recognized that large-scale feed companies have better ability to provide additional services to farmers, while small and medium-scale feed companies should provide better quality feed to win market share (Gao *et al.* 2010; Yang 2013; Yang & He 2012). For farmers, it's more like a trade-off between better quality feed and more services provided by feed companies.

Chemical use is more complex than feed. Many different chemicals were used in tilapia and shrimp farms, such as various antibiotics, disinfectants, parasiticides, feed additives and plant extracts, and probiotics (Rico *et al.* 2013). The aquaculture chemical market was mainly regulated by the GMP (Good Manufacturing Practice) and the GSP (Good Supply Practice) certification standards. However, many chemicals were labelled as "non-drug" to avoid GMP and GSP certifications, such as water quality regulation agents, plant extracts, and probiotics, those "non-drug" chemicals were loosely regulated and the quality was generally poor (Wang 2013).

Innovations in production technology were another type of important sustainability factor, which were believed by stakeholders to be potential solutions to existing problems. It was also ranked first among all the farmer proposed responses to negative sustainability factors. Some revolutionary technologies may provide important improvement to shrimp and tilapia farming, such as the novel shrimp automatic feeding machine that might not only reduce labour required, but also improving FCR and animal growth (Limsuwan & Ching 2013).

Many studies published in Chinese journals also reported some sustainability factors from a top down perspective. These sustainability factors cover social, economic, environmental and farming practice. In aspect of social, sustainability factors include imbalance developments of industry within different areas, low-level of industrialization of the whole value chain, small-scale and scattered farms, lack of producer organizations, and lack of unified planning by government. In aspect of economic, sustainability factors include lack of well–established and valuable brands, international competition, unstable export markets, lack of marketing channel, supply exceeding demand, and purchase of feed using expensive credit. In aspect of environmental mainly is environment impact caused by farms. In aspect of farming practice sustainability factors include poor pond infrastructure, lack of good shrimp broodstock as well as self-recruitment and inbreeding, disease, and inconsistent seed quality and feed quality (Chen 2010; Lei *et al.* 2009; Li 2006; Li 2009; Lin 2009; Zheng 2009; Zheng 2008; Yuan 2008). Most of these sustainability constraints were identified in this research.

6.4.4. Developing SIs

Around 40% SIs candidates were knocked out according to the SMART criteria, and 60% were found to fulfil the SMART criteria. However, the SMART criteria need to be developed further by adding accuracy and efficiency (Bondad-Reantaso *et al.* 2009). According to the new efficiency criteria, SIs at broader levels, such as value chain level and macro level, are more difficult to measure than those SIs at local or farm level. This also raised the question of who will use these SIs, as different stakeholders may focus on different levels of the value chain, they may be more efficient in using particular SI. For example, it may be more appropriate that farmers apply farm level SIs than government officers, while government officer are better able to apply SIs at the city level (Shen *et al.* 2011; Rametsteiner *et al.* 2011). The application of SIs could need the effort from the whole value chain. However, SIs developed in the SoS workshop were more focused on economic aspects, especially at the farm level. The unbalanced SIs is also reflected in differences in distribution among DPSIR framework. The unbalanced SIs reveals stakeholders perspective from a bottom-up approach. Obviously, the real world is far more complex than can be expressed in simple causal relations in systems analysis. There is arbitrariness in the distinction between the environmental system and the human system. Moreover, many of the relationships between the human system and the environmental system are not sufficiently understood or are difficult to capture in a simple DPSIR framework (Smeets & Weterings 1999). The proposed SIs also need to be tested in reality before using them (Choi & Turk 2011). Sustainability focus changes with the stage of development from social in developing countries to environmental in developed countries (OECD 2001), and SIs need to be adjusted over time (Rametsteiner *et al.* 2011).

7. CHAPTER 7: Comparative Life cycle assessment (LCA) for integrated and non- integrated tilapia farming in China

7.1. Introduction

China is the largest producer and exporter of tilapia (FAO 2012a). Farmed tilapia [mainly (*Oreochromis niloticus) a*nd hybrids of blue tilapia and Nile tilapia (*O. aureus* ♂ × *O. niloticus* ♀)] expanded quickly in recent years mainly focussing on export demand (Liu & Li, 2010). Although carps still dominate Chinese aquaculture, tilapia is now one of six finfish species for which more than one mmt is produced annually (Liu *et al.* 2011).

China is also the largest pig producer in the world, accounting for around half global pig meat production in 2012 (FAO 2014a). In 2013, total pig production in China was 54.93 mmt with year-on-year growth rate 2.5%, even higher than aquaculture production 45.47 mmt (NBS 2014).

There are many interactions between the terrestrial livestock and fisheries sectors which have been historically interdependent in the form of integrated agriculture aquaculture systems (IAAS) (Edwards 2011b; Edwards 2009; Edwards 2010; Little & Edwards 2003; Wang 2000). IAAS has a very long history in China, starting from aquatic plants and fish integrated systems in 200 BC and evolving to the famous mulberry-dike fish and livestock system in the 17th century, and still widely in practice in recent years (Li 2003; Ruddle & Zhong 1988). IAAS have been well developed and practised worldwide (Kumar & Ayyapan 1998), especially in Asia where much of the production is from traditional pond based IAAS with livestock wastes as the most commonly used input (Little & Edwards 2003; Muir 2005).

Traditional IAAS linked the reuse of waste nutrients from monogastric livestock, especially pigs, to their reuse in fertilised fishponds to enrich phytoplankton and zooplankton, which are food for a variety of fish (Edwards 2011b; Edwards 2009; Little & Edwards 2003; Taiganides 1979; Wang 2000; Wong *et al.* 2004). Compared with monocultures, IAAS has advantages in terms of increased diversification, intensification, improved natural resource efficiency, increased productivity, reduced input and waste disposal costs. Less space and time is used and reduced uncertainty linked to seasonality of income and nutrition may also be a benefit (Jiang & Zhao 2011; Kumar & Ayyapan 1998; Mamun *et al.* 2012; Prein 2002; Peng *et al.* 2006). Integration is a key element of the 'ecosystem approach to aquaculture (EAA)' which '*is a strategy for the integration of the activity within the wider ecosystem in such a way that it promotes sustainable development, equity, and resilience of interlinked social and ecological systems*' (Soto *et al.* 2008; Bostock *et al.* 2010). IAAS was seen as one option for economically and ecologically benign sustainable development and an alternative to specialised and separated commercial farming systems (Little & Edwards 2003; Noble 2009). Integrated farming systems can improve nutrition and food security, economic income, and social benefits of small-scale farmers in rural areas (Karim *et al.* 2011; Kumar & Ayyapan 1998; Little & Edwards 2003; Murshed-E-Jahan & Pemsl 2011; Prein & Ahmed 2000).

However, the use of animal excreta in aquaculture systems may lead to potential concerns regarding human health, product quality and food safety issues still requires further research (Mente *et al.* 2011). The export oriented CIQ registration system forbids integrated farming in all CIQ farms because of food safety concerns (China Entry-Exit Inspection and Quarantine Bureau 2004). In order to avoid health hazards caused by Salmonella or other food-pathogens, use of untreated animal manure as fertilizer is also forbidden by BAP certification (BAP 2008). However, many studies have indicated the low potential food safety risks of such systems (e.g. Edwards

2001). A recent study has shown the risks for fishborne zoonotic trematodes in tilapia integrated system were no different to those in non-integrated system, and lower than the risk those from water bodies in the general environment (Li *et al.* 2013).

Integrated systems remain important for some species in some areas in China, suggesting the approach remains relevant in contexts where industrialization and urbanization, together with a fast growing livestock sector are co-located (Little & Edwards 2003). At the same time, organic aquaculture, considered part of IAA, has become increasingly popular in China (Xie *et al.* 2013). Most organic aquaculture is based on more extensive farming system in which external fertilizers such as organically produced livestock manures can be used to enhance natural productivity (Mente *et al.* 2011; Xie *et al.* 2013).

There were different opinions on pig manure, such as the debate of pig manure as resource or waste (Fleming *et al.* 1998). Traditionally pig manure is one kind of organic fertilizer being wildly used in agriculture (Burton & Turner 2003). Pig manure also is one kind of resources which can produce biogas through fermentation (Deublein & Steinhauser 2011). Rather than thinking of pig manure as one kind of “waste”, it is better to consider it as “*resources out of place*” (Taiganides 1979). However, accompanying the rapid expansion of pig farming, pig manure has become one of major pollution source in some area in China (Fang *et al.* 2013; Mo *et al.* 2011; Zheng *et al.* 2012; Zhu *et al.* 2011).

Despite a history of waste reuse in IAAS, nutrient losses from aquaculture production, especially as they have tended to become more intensive with the use of formulated diets in addition to manure have become an issue. Waste water commonly drains into the external environment from semi-intensive farming systems without treatment or recycling, which can result in some level of environmental impact on receiving water. Perhaps more significantly such types of aquaculture also contribute to broader environmental impacts such as climate change through greenhouse gas (GHG) emissions. The main source of GHG emissions in the aquaculture sector is fossil fuel derived CO_2. However, carbon footprint has to be understood in a wider context, where GHG emissions may not be the main environmental concern for a particular system (Vázquez-Rowe *et al.* 2012).

Along with globalisation, environmental problems can shift from one site to another or from the local scale to global scale (Ayer & Tyedmers 2009; Boons *et al.* 2012; Bostock *et al.* 2010; López *et al.* 2013). A more holistic sustainability measurement tool is needed to resolve environmental problems at different scales along the value chain. Recently Life Cycle Assessment (LCA), based on the life cycle approach, has emerged as a scientifically-based and product-oriented environmental impact assessment tool (Mungkung & Gheewala 2007), and has become increasingly used for aquaculture development assessment (Ayer & Tyedmers 2009; Henriksson *et al.* 2011).

LCA is a well-developed and ISO-standardized, indicator-based quantitative methods to evaluate environmental performance and energy and material efficiency of food production systems (Diana *et al.* 2013; Finkbeiner *et al.* 2006; ISO 2006b; ISO 2006a; van der Werf & Petit 2002). LCA includes impact assessment of all actions and means required to produce, distribute and use a product, from raw material use, infrastructures, energy, processing and all the emissions (in air, water and soil) linked to the product or process (Martins *et al.* 2010; Mungkung & Gheewala 2007). LCA offers a systematic way to comprehensively describe environmental impacts of a product chain, and it can be done at different scales, stages and geographical areas, and identify environment impact migrations (Ayer & Tyedmers 2009; Boons *et al.* 2012; Cao *et al.* 2011)

LCAs of aquaculture systems are an emerging area, and research is needed to assess the global performance of the diverse systems and settings for aquaculture (Diana *et al.* 2013). LCA is one of the key approaches to make ecological efficiency assessments in aquaculture systems and a ready comparison between products and helps to identify stages in the product life cycle where efficiency gains might be realized (Bostock *et al.* 2010). By quantifying the environmental impacts over the entire life cycle of a farmed seafood product, LCA provides more comprehensive information of the environmental implications of these technologies (Ayer & Tyedmers 2009). In China, LCAs on both system and national levels are urgently required to identify hot spots and best practice to inform future development (Zhang *et al.* 2014).

LCA is primarily an environmental assessment tool, it doesn't include temporal and geographical differences as well as social and economic aspects (Mungkung & Gheewala 2007). Although the concept of social LCA and life cycle sustainability assessment which combine both LCA and LCC have emerged in the last few years (Benoît *et al.* 2010; Jørgensen & Bocq 2008; Kloepffer 2008), they are not widely used. Most LCA do not include evaluations of social aspects of sustainability and are not suitable for detailed farming practice analysis (Diana *et al.* 2013).

The type and purpose of any LCA is determined by the methodological choices; while ‘ordinary’ LCA has principally been a methodology for comparing equivalent product systems (Boons *et al.* 2012), comparative LCA studies have been used to evaluate different production systems or choice of management strategies to identify the most environmentally-preferred system or option. The results of the latter can support many applications such as eco-labelling, eco-design, and cleaner production (Boons *et al.* 2012; Mungkung & Gheewala 2007).

LCA is based on four stages, namely “goal and scope definition”, “inventory analysis”, “impact assessment” and “interpretation” (ISO 2006a). At goal and scope definition stage, LCA approaches can be divided into two modes, namely attributional LCA, and consequential LCA. Attributional LCA, also referred to as status-quo or descriptive LCA, is defined by its focus on describing the environmentally relevant physical flows to and from a life cycle and its subsystems. Consequential LCA is defined by its aim to describe how environmentally relevant flows will change in response to possible decisions (Guinée *et al.* 2010; Vázquez-Rowe *et al.* 2012).

The life cycle inventory analysis (LCI) stage mainly includes functional unit and system boundary setting, data collection, and allocation. The functional unit describes the main function(s) fulfilled by a production system and indicates how much of this function is considered. In comparative LCAs the functional unit is the reference for the comparison. The setting of system boundaries specifies which unit processes are part of a product system (Guinée *et al.* 2002; ISO 2006a). Allocation is needed to deal with systems involving multiple products and recycling systems (ISO 2006a), which mainly have two possible alternatives between mass allocation by their physical properties or economic allocation by their economic value (ISO 2006b; Vázquez-Rowe *et al.* 2012). In this case, the system boundaries setting and allocation is critical between inclusive of pig manure or not and allocation of waste could make great differences.

The Life Cycle Impact Assessment (LCIA) is aimed at evaluating the significance of potential environmental impacts using the LCI results (ISO 2006a). The major LCIA methodology used for characterization in aquaculture and fisheries studies was the midpoint CML baseline method (Henriksson *et al.* 2011; Vázquez-Rowe *et al.* 2012), which is a problem-oriented approach in a cause-effect chain (Guinée *et al.* 2002). Commonly used impact categories in aquaculture studies include global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), and cumulative energy demand (CED), with a few novel impact categories such as biotic resource use, human toxicity, and freshwater aquatic ecotoxicity (Henriksson *et al.* 2011).

The final interpretation stage mainly includes contribution analysis (gravity analysis), uncertainty analysis and sensitivity analysis (Henriksson *et al.* 2011; ISO 2006b; Vázquez-Rowe *et al.* 2012). Contribution analysis can be used to identify shares of a certain product in environmental impacts or "hot spots" (processes or interventions with relatively high impacts) of a certain product system. The uncertainty analysis uses empirical data on the uncertainty ranges of specific data to calculate the total error range of the results and how they affect the reliability. Sensitivity analysis is a procedure to determine how changes in data and methodological choices affect the results of the LCIA (Guinée *et al.* 2002; ISO 2006b).

Results in chapter 5 indicated that IAAS were still common for tilapia farming in Guangdong province, especially tilapia-pig integrated system. The tilapia-pig IAAS has also become intensified. However, compared to traditional systems as large amounts of formulated fish feeds are given in addition to manure; no IAAS farm was found without additional feed input. However, integrated farms tend to use cheaper feeds (Chapter 5) with lower protein level. At present, there are very few studies on China's tilapia and pig farming sustainability measurement from a life cycle perspective. In this study, attributional LCA was used to assess the environmental performance of tilapia, pig and integrated tilapia-pig farming systems in China.

7.2. Methodology

The LCA methodological framework developed by SEAT project was applied (Henriksson *et al.* 2011;

Guinée *et al.* 2010; Henriksson *et al.* 2013).

7.2.1. Goal and scope

The present study tried to determine environmental performance of a typical aquaculture integrated systems in China, the tilapia-pig integrated system, and compare with tilapia non-integrated system and pig farming system separately. The goal and scope is the first step of LCA, which the temporal, spatial and technology coverage and functional unit was set (ISO 2006a).

An attributional LCA approach was adopted in this study.

Temporal coverage was set as the whole calendar year in 2009 for farm and 2010 for hatcheries, feed mills, fishing fleets and fishmeal plants.

Spatial coverage is Maoming district, Guangdong Province, China.

Technology coverage is tilapia-pig integrated system, tilapia non-integrated system and pig farming system. Most tilapia farming systems, regardless of integrated or not, are tilapia and carps polyculture system, and by definition they are semi-intensive systems. Pig farms vary from small-scale operations with a few pigs to large-scale with more than 1000 pigs.

The functional unit was set at one mt of primary product at the farm gate i.e.for tilapia s one mt of live tilapia, for pig, one mt live pig.

7.2.2. Inventory analyses

7.2.2.1. System boundary and scenarios

The system boundary was set at the farm gate level. The whole system was divided into three sections (Figure1), section 1 tilapia farming, section 2 pig manure come from pig farms, and section 3 is pig farm. Based on these sections, five scenarios were set according to different boundary settings.

Scenario 1 is non-integrated CIQ pond tilapia farms (hereafter CIQ) included within Section 1 in Figure 7.1;

Scenario 2 is non-integrated non-CIQ pond tilapia farms (hereafter TP) included within Section 1;

Scenario 3 is medium and large-scale integrated tilapia farms with pig farming excluded due the focus on tilapia farming and in order to facilitate comparison between different tilapia farming systems without the complication of pig farming (hereafter TIML), included within Section 1 and 2;

Scenario 4 is small-scale integrated tilapia farms with pig farming excluded (hereafter TIS) included within Section 1 and 2;

Scenario 5 is pig farms (hereafter PIG), which is included within Section 2 and 3.

The value chain beyond the farm gate is not included in this study. We can also assume there will be no difference post farm gate. Infrastructure is often excluded for LCA studies because their contribution to the overall environmental burden of the product is typically less than 5% due to their long lifespan (Mungkung & Gheewala 2007), and is also not included in this study.

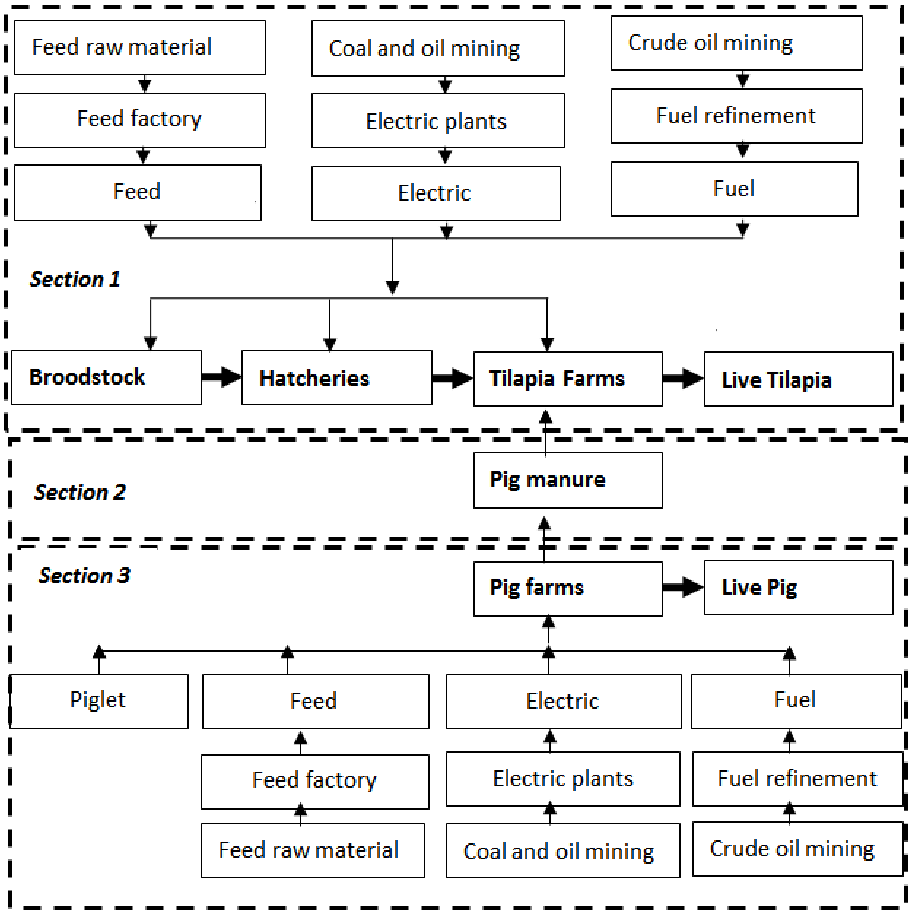


Figure 7.1 System boundary setting and different sections for different scenarios.

7.2.2.2. Data collection

Primary data from tilapia farms were collected during the SEAT baseline survey (see Chapter 5).

SEAT baseline survey found that the most popular integrated tilapia farming system was the tilapia – pig integrated system. To avoid any possible bias, only farms in Maoming district, Guangdong province were selected for this study, and all reservoir farms and farms integrated with chicken or duck or with pigs present on the farm but not integrated with fish production on the farm were excluded in order to remove possible bias.

Primary data from tilapia hatcheries, tilapia feed mills, fishing fleets and fishmeal plants were collected during a field survey in 2011 (Henriksson *et al.* 2014).

Secondary data were collected from journal papers, books, reports and online databases. Ecoinvent® database version 3.0 was used to provide baseline background data. Background data, such as agricultural products and feed raw materials based on Chinese production systems, were collected including country-specific energy data (Henriksson *et al.* 2014). Pig production was based on secondary sources; data on concentrate feed ingredients (Cao *et al.* 2008; He 2008), formulated diets (Li *et al.* 2003; Liu *et al.* 2009; Liu *et al.* 2012; Wang 2010; Wang 2012; Xie *et al.* 2009; Ye *et al.* 2011;Yue & Wang 2011; Zhao 2008; Zheng *et al.* 2013), feed types used in farm (Huang *et al.* 2010; Liu *et al.* 2011; NDRC 2013; Yang & Xiao 2010), pig farming practice (Bai *et al.* 2009; Guo *et al.* 2013; Liu *et al.* 2011; Liu *et al.* 2012; NDRC 2013; Zhao 2008; Wang 2010; Zheng *et al.* 2013), pig manure (Guo *et al.* 2011; MOE 2009; MOA 2009; Yang *et al.* 2011), and pig manure storage and destination (Chen & Zheng 2013; Chou 2013; Fang *et al.* 2013; Jiang 2011; Liu *et al.* 2008; Liu *et al.* 2011; Mo *et al.* 2011; Xu & Chen 2006; Yang *et al.* 2010; Yang *et al.* 2013; Zhang *et al.* 2011; Zheng *et al.* 2012; Zheng *et al.* 2012; Zhu *et al.* 2011).

Pig production was estimated based on pig herd size and profiles collected in the national survey conducted by government, the five year (2008-2012) average pig slaughter and pig stock ratio 1.4018, and the five year (2008-2012) average pig weight at slaughter 114.49 kg (NSBC 2013; NDRC 2013). For integrated systems, pig farming practice and feed, electricity and fuel consumption data were calculated based on estimated pig production data. In order to compare tilapia integrated and non-integrated systems, electricity consumption at integrated farms was recalculated using total electricity consumption minus estimates of standalone pig farming electricity consumption.

7.2.2.3. Allocation

Different allocation methods have a large influence on the absolute results of the individual LCA model, but much less influence on relative differences between LCAs (Henriksson *et al.* 2014). Allocation in this study is based on physical (mass) allocation, and economic allocation was not adopted as it did not provide any greater information for farming system comparison.

7.2.3. Life Cycle Impact Assessment (LCIA)

CML (2001) baseline method was adopted for Life Cycle Impact assessment (LCIA) (Guinée *et al.* 2002), and CMLCA v5.2 software was employed (http://www.cmlca.eu/).

Impact categories of this study included global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), cumulative energy demand (CED), abiotic depletion (element) (AD), human toxicity potential (HTP), freshwater aquatic ecotoxicity potential (FAETP), marine aquatic ecotoxicity potential (MAETP), terrestrial ecotoxicity potential (TETP), ozone layer depletion potential (ODP), and photochemical oxidation potential (POP).

The AMOEBA - type diagram was made in qualitative terms to compare the environmental impacts of different scenarios. The highest value in each impact category was set as the reference value, and percentages of impact values of different farming systems were calculated based on the reference values. All calculated values (percentages based on reference value) were presented as AMOEBA diagrams, where higher values (or closer to the outer ring, which represents 100% of reference value) mean higher environmental impact.

7.2.4. Interpretation

Interpretation is a phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are combined consistent with the defined goal and scope in order to reach conclusions and recommendations (ISO 2006a).

7.2.4.1. Contribution analysis

In this study, contribution analyses were performed at all relevant levels (inventory analysis, characterization) and for different elements (processes and interventions). The results of these analyses were used for tracing possible errors and as a basis for identifying improvement options.

7.2.4.2. Uncertainty analysis

Quantified uncertainties (inherent uncertainties (inaccurate measurements) and spread (variability around means)) and representativeness were estimated using the protocol for horizontal averaging of unit process data (Henriksson *et al.*, 2013).

Uncertainty analysis was based on 1000 Monte-Carlo simulations in CMLCA software. SPSS 21 (IBM 2014) and independent-samples Kruskal-Wallis test was adopted for the significance test.

7.2.4.3. Sensitivity analysis

Based on LCIA and contribution analysis results, sensitivity analyses were conducted. Four different scenarios were designed based on CIQ farms and alternative electricity supply, lower eFCR, and lower fishmeal level tilapia feed. The first scenario is “EU electricity”, which uses EU average electricity supply to replace all local electricity supply. The second scenario is “5% lower eFCR”, which is 5% higher feed efficiency. The third scenario is “10% lower eFCR”, which is 10%

higher feed efficiency. The last scenario is "1% fishmeal feed", where fishmeal content in the tilapia feed model is reduced from 6.8% to 1%. The effect of these changes on LCIA results was examined using 1000 times Monte-Carlo simulations and independent-samples Kruskal-Wallis test to check significances.

7.3. Results

7.3.1. Life cycle inventory

Ninety four tilapia farms in the baseline survey were selected for this study, including seven CIQ (non-integrated CIQ pond tilapia farms) farms, 17 TP (non-integrated non-CIQ pond tilapia farms) farms, 20 TIML (medium and large-scale integrated tilapia farms with pig farming excluded) farms, and 50 TIS (small-scale integrated tilapia farms with pig farming excluded) farms. Based on primary and secondary data, the economic inflows, and economic outflows were calculated (Table 7.1). To produce one mt live-weight tilapia or pig, the CIQ farms had the highest electricity and tilapia feed input, but PIG farms had higher eFCR than all tilapia farms. The TIS farms had the lowest feed input, but the electricity input was higher than TP and TIML farms.

Table 7.1 Economic inflows, and economic outflows for production of one mt live-weight tilapia or pig from the five modelled scenarios

		CIQ	TP	TIML	TIS	PIG
Economic inflows	Electricity (kWh)	836	509	413	738	99.3
	CV	L(1.27)	L(0.744)	L(0.936)	L(1.32)	L(0.552)
	Tilapia feed (kg)	1.65E+03	1.51E+03	1.57E+03	1.39E+03	
	CV	L(0.324)	L(0.294)	L(0.174)	L(0.282)	
	Pig feed (kg)					3.02E+03
	CV					L(0.106)
	Diesel (kg)	0.818	1.07	3.31	2.83	2.55
	CV	L(2.02)	L(2.75)	L(2.92)	L(3.2)	-
	Petrol (kg)		1.02	0.263	0.594	4.36
	CV		L(2.35)	L(4)	L(5.24)	L(0.0503)
	Hard coal (MJ)					7.80E+03
	CV					L(1.04)
	Tilapia fry (pieces)	1430	1402	1740	2122	
	CV	L(0.563)	L(0.725)	L(0.387)	L(0.732)	
Economic outflows	Tilapia (kg)	1.00E+03	1.00E+03	1.00E+03	1.00E+03	
	CV	-	-	-	-	
	Carp (kg)	60	60	60	60	
	CV	L(0.433)	L(0.433)	L(0.433)	L(0.433)	
	Pig (kg)					1.00E+03
	CV					L(0.187)
	Pig manure (kg)					4.32E+03
	CV					N(25)

Note: CV= Coefficients of Variation, L=Lognormal distribution, N=Normal distribution, CIQ=non-integrated CIQ pond tilapia farms, TP=non-integrated non-CIQ pond tilapia farms, TIML=medium and large-scale integrated tilapia farms with pig farming excluded, TIS=small-scale integrated tilapia farms with pig farming excluded, PIG=pig farms

As previous studies showed feed is the most important component of the overall impacts for all other impact categories (Pelletier & Tyedmers 2010; Ayer & Tyedmers 2009), the feed ingredients and energy input were listed in Appendix 5. Tilapia feed was mainly commercial pelleted feed, but pig feed included concentrates feed[10], pelleted feed, and feed raw materials such as grains.

10 Concentrates are feeds that contain a high density of nutrients, usually low in crude fibre content (less than 18% of dry matter (DM)) and high in total digestible nutrients that was mixed with other feed raw materials such as corn before use (Hendy et al. 1995)

7.3.2. LCIA with uncertainty analysis

Results of LCIA with uncertainty analysis for production of one mt live-weight tilapia or pig from the five modelled scenarios were listed in Table 7.2.

Table 7.2 CML baseline characterisation results for production of one mt live-weight tilapia or pig from the five modelled scenarios (Mean ± SD)

Impact categories	CIQ	TP	TIML	TIS	PIG
GWP (kg CO2 eq.)	4.35E+03	3.58E+03	3.58E+03	3.56E+03	8.40E+03
	±2.94E+03	±1.30E+03	±1.06E+03	±1.93E+03	±2.10E+03
CED (MJ)	4.72E+04	3.67E+04	3.62E+04	3.70E+04	4.47E+04
	±6.49E+04	±2.55E+04	±1.84E+04	±3.65E+04	±2.89E+04
AP (kg SO2 eq.)	4.43E+01	3.84E+01	3.97E+01	3.63E+01	9.75E+01
	±1.96E+01	±1.31E+01	±1.02E+01	±1.30E+01	±2.50E+01
EP (kg PO4 eq.)	6.42E+01	5.72E+01	6.69E+01	5.83E+01	6.63E+01
	±1.82E+01	±1.28E+01	±1.87E+01	±1.80E+01	±2.39E+01
HTP	1.30E+03	1.06E+03	1.02E+03	1.07E+03	1.43E+03
(kg 1,4-dichlorobenzene eq.)	±1.07E+03	±4.85E+02	±4.00E+02	±7.53E+02	±5.61E+02
TETP	4.06E+01	3.34E+01	3.32E+01	3.29E+01	2.35E+01
(kg 1,4-dichlorobenzene eq.)	±3.12E+01	±1.21E+01	±9.80E+00	±1.65E+01	±7.52E+00
FAETP	6.38E+02	5.05E+02	4.97E+02	5.24E+02	5.77E+02
(kg 1,4-dichlorobenzene eq.)	±6.84E+02	±3.25E+02	±2.77E+02	±4.79E+02	±4.11E+02
MAETP	3.95E+06	3.06E+06	2.91E+06	3.20E+06	4.26E+06
(kg 1,4-dichlorobenzene eq.)	±4.42E+06	±1.86E+06	±1.43E+06	±2.56E+06	±2.16E+06
ODP (kg CFC-11 eq.)	2.18E-04	1.95E-04	2.02E-04	1.80E-04	3.01E-04
	±1.26E-04	±1.07E-04	±9.24E-05	±9.31E-05	±1.72E-04
POP (kg ethylene eq.)	9.06E-01	7.69E-01	7.83E-01	7.44E-01	1.65E+00
	±5.43E-01	±3.10E-01	±2.50E-01	±3.56E-01	±6.22E-01
AD (kg antimony eq.)	4.40E-03	3.67E-03	3.76E-03	3.55E-03	4.60E-03
	±2.83E-03	±1.54E-03	±1.46E-03	±1.76E-03	±2.29E-03

Note: GWP=global warming potential, AP=acidification potential, EP=eutrophication potential, CED=cumulative energy demand, AD=abiotic depletion (elements), HTP=human toxicity potential, FAETP=Freshwater aquatic ecotoxicity potential, MAETP=Marine aquatic ecotoxicity potential, TETP=Terrestrial ecotoxicity potential, ODP=ozone layer depletion potential, POP=photochemical oxidation potential, CIQ=non-integrated CIQ pond tilapia farms, TP=non-integrated non-CIQ pond tilapia farms, TIML=medium and large-scale integrated tilapia farms with pig farming excluded, TIS=small-scale integrated tilapia farms with pig farming excluded, PIG=pig farms

PIG farms had the highest GWP than all types of tilapia farms, and CIQ farms had highest GWP of all types of tilapia farms (P<0.01). PIG farms and CIQ farms had higher CED than TP, TIML, TIS farms (P<0.01), but no difference between PIG farms and CIQ farms, and no difference between TP, TIML, and TIS farms (P>0.05).

PIG farm also had higher AP than all tilapia farms, the CIQ farms and TIML farms had higher AP than TP and TIS farms, and TP farms had higher AP than TIS farms (P<0.01). There was no difference between CIQ farms and TP farms (P>0.05). PIG farms, CIQ farms and TIML farms had higher EP than TP and TIS farms (P<0.01) and there was no difference between PIG, CIQ and TIML farms or between TP and TIS farms (P>0.05).

PIG farms had higher HTP than all tilapia farms, CIQ farms had higher HTP than other tilapia farms (P<0.01), no difference between TP, TIML, TIS farms (P>0.05). CIQ farms had higher TEP than PIG farms and all other tilapia farms (P<0.01), TP and TIML farms had higher TEP than TIS farms (P<0.05) and PIG farms (P<0.01), and TIS farms had higher TEP than PIG farms (P<0.01). No differences were found between TP and TIML farms (P>0.05).

CIQ farms and PIG farms had higher FAETP than other tilapia farms (P<0.01), no difference was found between CIQ and PIG farms or between TP, TIML and TIS farms (P>0.05). PIG farms had higher MAETP than all tilapia farms, CIQ farms had higher MAETP than other tilapia farms (P<0.01), and no differences were found between TP, TIML and TIS farms (P>0.05).

PIG farms had higher ODP than all tilapia farms (P<0.01), and CIQ and TIML farms had higher ODP than TP and TIS farms (P<0.05). TP farms also had higher ODP than TIS farms (P<0.05). No difference was found between CIQ farms and TIML farms (P>0.05). Pig farms had higher POP than all tilapia farms, CIQ farms had higher POP than all other tilapia farms, and TIML farms higher than

TIS farms (P<0.01). No differences were found between TP and TIML farms or between TP and TIS farms (P>0.05).

PIG farms had higher AD than all tilapia farms (P<0.01), CIQ farms had higher AD than all other tilapia farms (P<0.01), TP and TIML farms also had higher AD than all other tilapia farms (P<0.05) and no differences were found between TP farms and TIML farms (P>0.05).

AMOEBA analysis also shows the relative comparison of all life cycle environmental impacts. PIG farms had the highest environmental impacts in most of categories, other than for FAETP and TETP was not the highest. Tilapia farms had a much lower life cycle environmental impact, especially for GWP, AP, ODP and POP, which only accounted for 40 – 60% of the environmental impact of PIG farms. Among all tilapia farms, CIQ farms had the highest environmental impact (Figure 7.2).

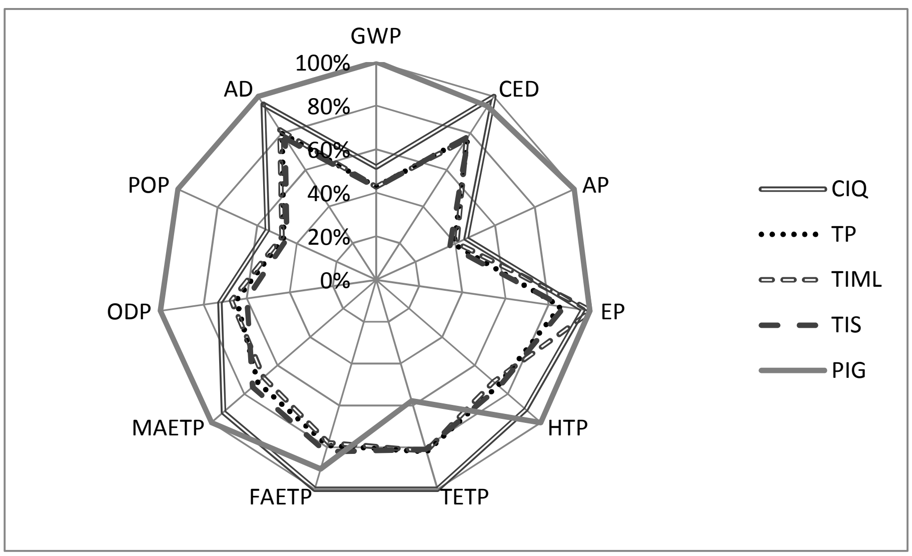


Figure 7.2 AMOEBA analysis of CML baseline characterisation results for production of one mt live-weight tilapia or pig from the five modelled scenarios

(GWP=global warming potential, AP=acidification potential, EP=eutrophication potential, CED=cumulative energy demand, AD=abiotic depletion (elements), HTP=human toxicity potential, FAETP=Freshwater aquatic ecotoxicity potential, MAETP=Marine aquatic ecotoxicity potential, TETP=Terrestrial ecotoxicity potential, ODP=ozone layer depletion potential, POP=photochemical oxidation potential, CIQ=non-integrated CIQ pond tilapia farms, TP=non-integrated non-CIQ pond tilapia farms, TIML=medium and large-scale integrated tilapia farms with pig farming excluded, TIS=small-scale integrated tilapia farms with pig farming excluded, PIG=pig farms)

7.3.3. Interpretation

7.3.3.1. Contribution analysis

For CIQ farms, feed contributed the biggest proportion in all impact categories, followed by electricity. Farming practice (farm level activities) contributed 45% of EP, but only accounted for the very low proportions in other impact categories (Figure 7.3).

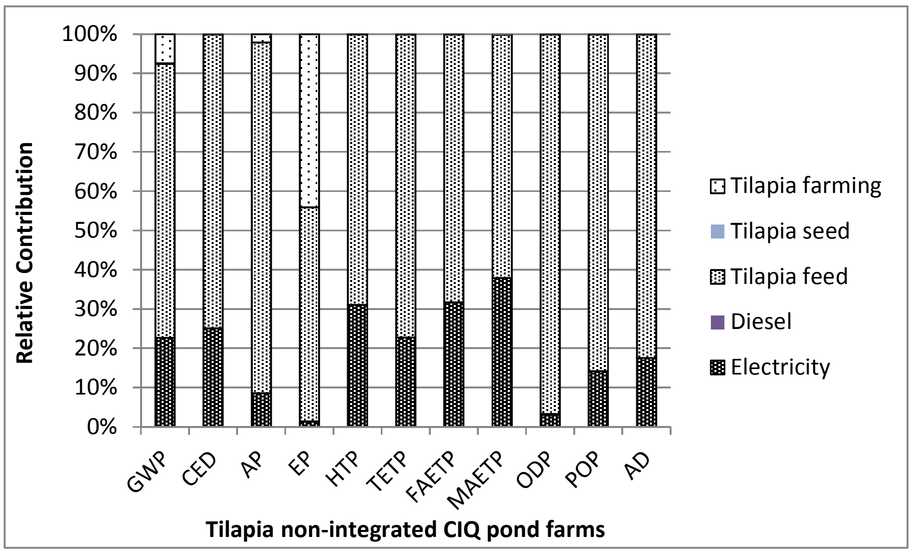


Figure 7.3 Contribution analysis for all impact categories of non-integrated CIQ pond tilapia farms

(GWP=global warming potential, AP=acidification potential, EP=eutrophication potential, CED=cumulative energy demand, AD=abiotic depletion (elements), HTP=human toxicity potential, FAETP=Freshwater aquatic ecotoxicity potential, MAETP=Marine aquatic ecotoxicity potential, TETP=Terrestrial ecotoxicity potential, ODP=ozone layer depletion potential, POP=photochemical oxidation potential)

For TP farms, feed contributed the biggest proportion in all impact categories, followed by electricity. Farming practice contributed 45% of EP and around 8% of GWP, but only accounted for the very low proportion in other impact categories (Figure 7.4).

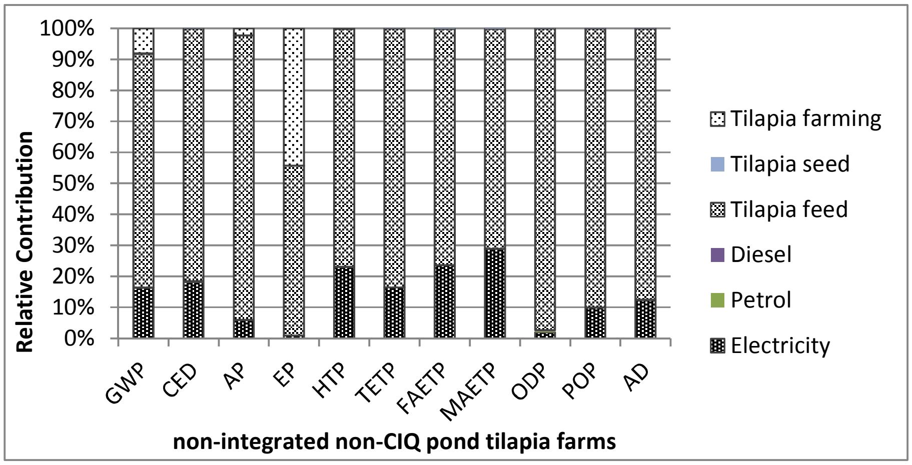


Figure 7.4 Contribution analysis for all impact categories of non-integrated non-CIQ pond tilapia farms

(GWP=global warming potential, AP=acidification potential, EP=eutrophication potential, CED=cumulative energy demand, AD=abiotic depletion (elements), HTP=human toxicity potential, FAETP=Freshwater aquatic ecotoxicity potential, MAETP=Marine aquatic ecotoxicity potential, TETP=Terrestrial ecotoxicity potential, ODP=ozone layer depletion potential, POP=photochemical oxidation potential)

For TIML farms, feed contributed the biggest proportion in all impact categories, followed by electricity. Farming practice contributed 50% of EP and around 9% of GWP, but only accounted for a very low proportion in other impact categories (Figure 7.5).

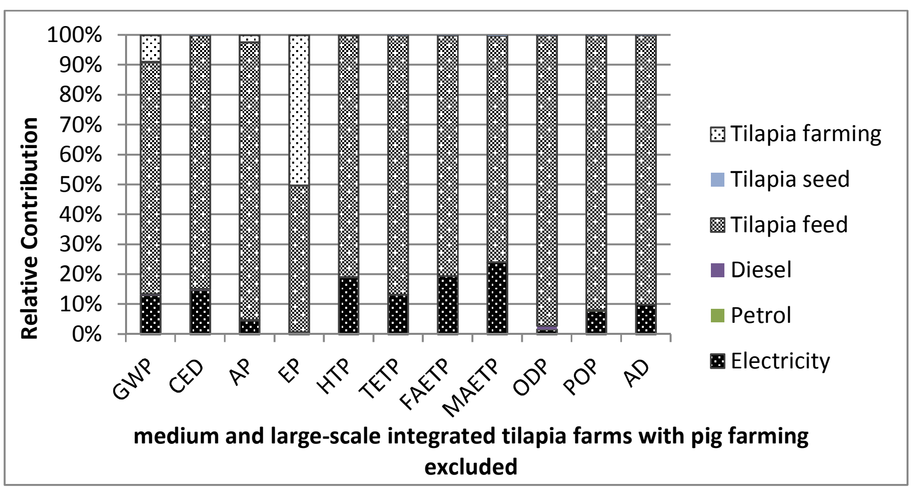


Figure 7.5 Contribution analysis for all impact categories of medium and large-scale integrated tilapia farms with pig farming excluded

(GWP=global warming potential, AP=acidification potential, EP=eutrophication potential, CED=cumulative energy demand, AD=abiotic depletion (elements), HTP=human toxicity potential, FAETP=Freshwater aquatic ecotoxicity potential, MAETP=Marine aquatic ecotoxicity potential, TETP=Terrestrial ecotoxicity potential, ODP=ozone layer depletion potential, POP=photochemical oxidation potential)

For TIS farms, feed also contributed the biggest proportion in all impact categories, followed by electricity. Farming practice contributed 50% of EP and around 8% of GWP, but only accounted for very low proportion in other impact categories (Figure 7.6).

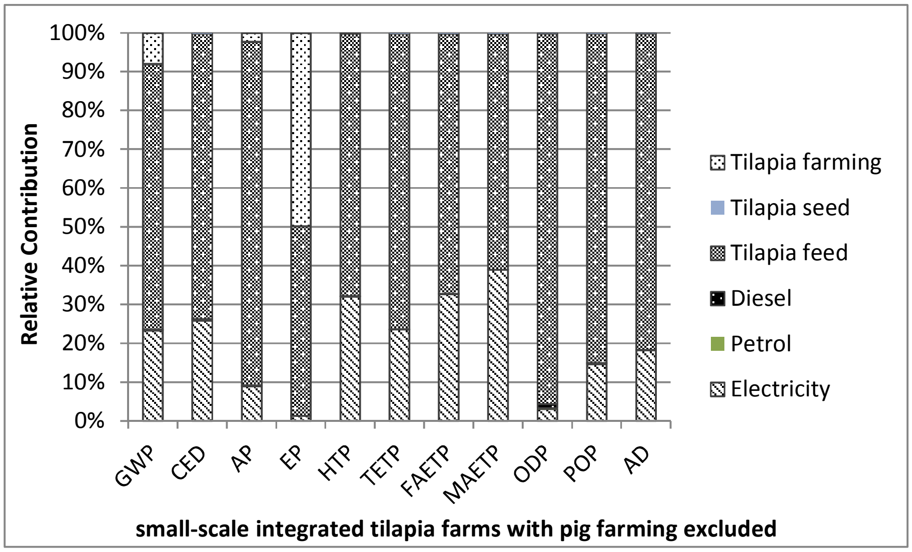


Figure 7.6 Contribution analysis for all impact categories of small-scale integrated tilapia farms with pig farming excluded

(GWP=global warming potential, AP=acidification potential, EP=eutrophication potential, CED=cumulative energy demand, AD=abiotic depletion (elements), HTP=human toxicity potential, FAETP=Freshwater aquatic ecotoxicity potential, MAETP=Marine aquatic ecotoxicity potential, TETP=Terrestrial ecotoxicity potential, ODP=ozone layer depletion potential, POP=photochemical oxidation potential)

For PIG farms, feed contributed the biggest proportion in all impact categories, followed by hard coal burning at the farm and pig farming (pig farm level activities). Electricity only accounted for less than 5% in all impact categories (Figure 7.7).

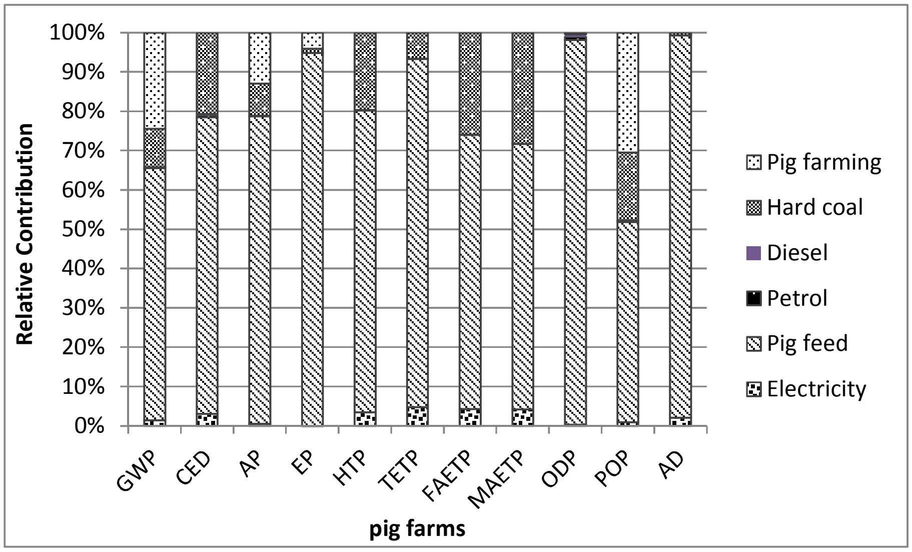


Figure 7.7 Contribution analysis for all impact categories of pig farms

(GWP=global warming potential, AP=acidification potential, EP=eutrophication potential, CED=cumulative energy demand, AD=abiotic depletion (elements), HTP=human toxicity potential, FAETP=Freshwater aquatic ecotoxicity potential, MAETP=Marine aquatic ecotoxicity potential, TETP=Terrestrial ecotoxicity potential, ODP=ozone layer depletion potential, POP=photochemical oxidation potential)

7.3.3.2. Sensitivity analysis

Sensitivity analysis shows "EU electricity" and "1% fishmeal feed" scenarios had a lower GWP than CIQ farms (P<0.01). The scenario "10% lower eFCR" also had a lower GWP (P<0.05), and no difference was found between "5% lower eFCR" and CIQ farms (P>0.05). The scenario "1% fishmeal feed" also had lower CED than original CIQ farms (P<0.01), but no difference was found between CIQ farms and "EU electricity", "5% lower eFCR" or "10% lower eFCR" (P>0.05).

The scenarios "1% fishmeal feed" and "10% lower eFCR" had lower AP than CIQ farms (P<0.01), "EU electricity" was also lower than CIQ farms (P<0.05), no difference between "5% lower eFCR" and CIQ farms (P>0.05). "10% lower eFCR" and "1% fishmeal feed" had a lower EP than CIQ farms (P<0.01), no difference between CIQ farms and "EU electricity" or "5% lower eFCR" scenarios (P>0.05).

The scenarios “EU electricity” and “1% fishmeal feed” had lower HTP than CIQ farms (P<0.01). No difference were found between CIQ farms and “5% lower eFCR” or “10% lower eFCR” (P>0.05). Only “10% lower eFCR” had lower TETP than CIQ farms (P<0.01). No differences were found between CIQ farms and “EU electricity”, “5% lower eFCR” or “1% fishmeal feed” (P>0.05).

The scenario “EU electricity” had higher FAETP than CIQ farms (P<0.01) and “1% fishmeal feed” had lower FAETP (P<0.01). No difference between CIQ farms and “5% lower eFCR” or “10% lower eFCR” (P>0.05). The scenario “EU electricity” and “1% fishmeal feed” had lower MAETP (P<0.01), no difference between CIQ farms and “5% lower eFCR” or “10% lower eFCR” (P>0.05).

The scenario “EU electricity” had higher ODP than CIQ farms (P<0.01) and “1% fishmeal feed” had lower ODP (P<0.01), no difference between CIQ farms and “5% lower eFCR” or “10% lower eFCR” (P>0.05). “EU electricity”, “1% fishmeal feed” and “10% lower eFCR” had lower POP tjan CIQ farms (P<0.01), no difference between CIQ farms and “5% lower eFCR” (P>0.05).

Only “10% lower eFCR” had lower AD than CIQ farms (P<0.05), no difference between CIQ farms and “EU electricity”, “5% lower eFCR” or “1% fishmeal feed” (P>0.05).

Table 7.3 Sensitivity analysis results for production of one mt live-weight tilapia (Mean ± SD)

	Original CIQ	EU electricity	5% lower eFCR	10% lower eFCR	1%fishmeal feed
GWP (kg CO2 eq.)	4.35E+03 ±2.94E+03	3.32E+03 ±1.40E+03	3.88E+03 ±1.98E+03	3.76E+03 ±1.68E+03	3.41E+03 ±1.85E+03
CED (MJ)	4.72E+04 ±6.49E+04	3.68E+04 ±1.86E+04	4.15E+04 ±3.24E+04	3.76E+04 ±2.47E+04	3.34E+04 ±2.21E+04
AP (kg SO2 eq.)	4.43E+01 ±1.96E+01	3.95E+01 ±1.38E+01	4.05E+01 ±1.50E+01	3.79E+01 ±1.28E+01	3.86E+01 ±1.32E+01
EP (kg PO4 eq.)	6.42E+01 ±1.82E+01	6.29E+01 ±1.57E+01	6.05E+01 ±1.47E+01	5.79E+01 ±1.31E+01	5.64E+01 ±1.22E+01
HTP (kg 1,4-dichlorobenzene eq.)	1.30E+03 ±1.07E+03	1.02E+03 ±5.64E+02	1.18E+03 ±8.06E+02	1.11E+03 ±6.25E+02	1.02E+03 ±6.42E+02
TETP (kg 1,4-dichlorobenzene eq.)	4.06E+01 ±3.12E+01	3.71E+01 ±1.88E+01	3.68E+01 ±1.85E+01	3.48E+01 ±1.53E+01	3.55E+01 ±1.74E+01
FAETP (kg 1,4-dichlorobenzene eq.)	6.38E+02 ±6.84E+02	7.23E+02 ±6.05E+02	5.72E+02 ±4.21E+02	5.47E+02 ±3.92E+02	4.95E+02 ±3.48E+02
MAETP (kg 1,4-dichlorobenzene eq.)	3.95E+06 ±4.42E+06	2.63E+06 ±1.81E+06	3.63E+06 ±2.80E+06	3.39E+06 ±2.41E+06	3.11E+06 ±2.98E+06
ODP (kg CFC-11 eq.)	2.18E-04 ±1.26E-04	2.49E-04 ±1.31E-04	2.02E-04 ±1.04E-04	1.88E-04 ±8.50E-05	1.81E-04 ±8.59E-05
POP (kg ethylene eq.)	9.06E-01 ±5.43E-01	7.80E-01 ±3.08E-01	8.21E-01 ±3.55E-01	7.59E-01 ±3.03E-01	7.18E-01 ±2.85E-01
AD (kg antimony eq.)	4.40E-03 ±2.83E-03	4.15E-03 ±2.26E-03	3.96E-03 ±1.95E-03	3.76E-03 ±1.81E-03	3.90E-03 ±1.79E-03

Note: GWP=global warming potential, AP=acidification potential, EP=eutrophication potential, CED=cumulative energy demand, AD=abiotic depletion (elements), HTP=human toxicity potential, FAETP=Freshwater aquatic ecotoxicity potential, MAETP=Marine aquatic ecotoxicity potential, TETP=Terrestrial ecotoxicity potential, ODP=ozone layer depletion potential, POP=photochemical oxidation potential, CIQ=non-integrated CIQ pond tilapia farms

AMOEBA graphs shows the relative comparison of sensitivity analysis results. Only the "EU electricity" scenario exceeded the original CIQ scenario baseline in ODP and FAETP, and all other scenarios were lower than the original CIQ scenario baseline (Figure 7.8).

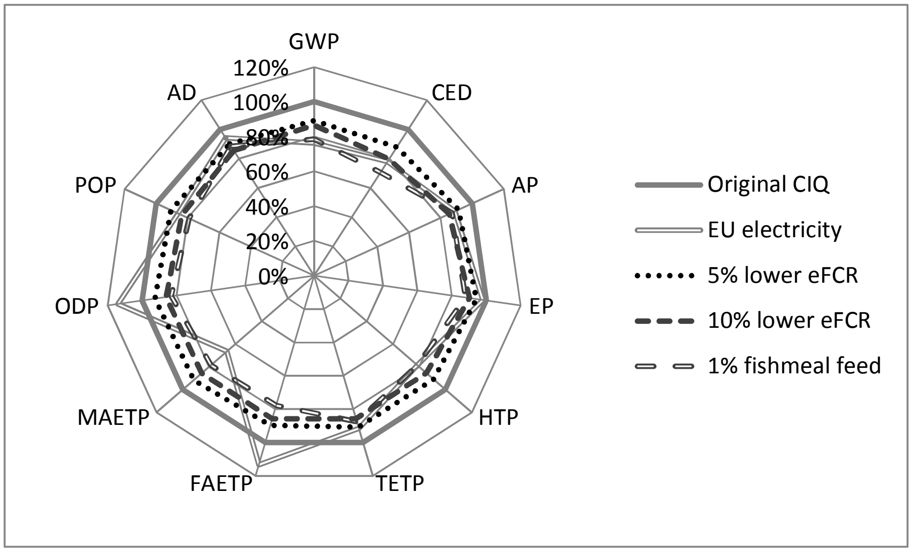


Figure 7.8 AMOEBA graph of sensitivity analysis results of different scenarios with original CIQ scenario as baseline (100% line in the graph)

(GWP=global warming potential, AP=acidification potential, EP=eutrophication potential, CED=cumulative energy demand, AD=abiotic depletion (elements), HTP=human toxicity potential, FAETP=Freshwater aquatic ecotoxicity potential, MAETP=Marine aquatic ecotoxicity potential, TETP=Terrestrial ecotoxicity potential, ODP=ozone layer depletion potential, POP=photochemical oxidation potential)

7.4. Discussion

7.4.1. LCIA results, and compared with other studies

Among all research farming systems, pig farming was found to have highest environmental impacts in most categories, while CIQ farms were also higher than other tilapia farms. The major reason was their higher feed inputs as feed accounted for most environmental impacts.

LCA results are significantly affected by different methodology choices and the background database used (Henriksson *et al.* 2011; Mungkung & Gheewala 2007; Vázquez-Rowe *et al.* 2012). In this study, background data were collected for feed ingredients such as domestic fishmeal and crop plants. China specific energy sources, especially electricity generating, may cause big differences. Sensitivity analysis also revealed the “EU electricity” scenario performed better in most of impact categories with significant differences. This is due to significant differences in electricity supply structure between China and Europe (BP 2013), and different electricity supply structure has significant effect on LCA studies (Henriksson *et al.* 2014). Coal power plants provided 78.7% of the electricity consumed in China in 2012, followed by 17% hydro power, 2% nuclear and 2% wind power (China Electric Power Yearbook Editorial Department 2014). European electricity supplies are more reliant on fossil fuel fired power (52% in 2009), followed by nuclear (28%), hydro (12%) and renewables (8%) (Eurelectric 2011).

The LCIA results were compared to other similar studies and summarized in Table 7.4. The comparison shows tilapia farming in China caused higher environmental impacts on GWP, CED, AP, and EP than tilapia farming in Thailand and Indonesia and the difference is huge. The differences are more likely to result from use of different methodologies and background database used, rather than the nature of these farming systems. Pig farming also had higher environmental impacts than that in Germany and France, mainly due to higher FCR and different electricity sources in China.

Table 7.4 Comparison of Life Cycle Impact Assessment (LCIA) results of this study and other similar studies to produce one mt product

Species	Country	Farming system	Product form	GWP (kg CO_2 eq.)	CED (MJ)	AP (kg SO_2 eq.)	EP (kg PO_4 eq.)	References
Tilapia	China	CIQ	Live weight	4350	47200	44.3	64.2	This study
Tilapia	China	TP	Live weight	3580	36700	38.4	57.2	This study
Tilapia	China	TIML	Live weight	3580	36200	39.7	66.9	This study
Tilapia	China	TIS	Live weight	3560	37000	36.3	58.3	This study
Tilapia	Thailand	High density polyculture	Live weight	1253	20785	9.9	70	(Mungkung *et al.* 2013)
Tilapia	Thailand	Low density polyculture	Live weight	1444	23501	11.3	105	(Mungkung *et al.* 2013)
Tilapia	Indonesian	Lake	Live weight	1520	18200	20.2	47.8	(Pelletier & Tyedmers 2010)
Tilapia	Indonesian	Pond	Live weight	2100	26500	23.8	45.7	(Pelletier & Tyedmers 2010)
Shrimp	China	Intensive monoculture	Live weight	5280	61500	43.9	63	(Cao *et al.* 2011)
Shrimp	China	Semi-intensive monoculture	Live weight	2750	34200	19.4	32.3	(Cao *et al.* 2011)
Striped catfish	Vietnam	Pond intensive	Live weight	8930	13200	48.1	65	(Bosma *et al.* 2011)
Striped catfish	Vietnam	Pond intensive	Live weight	8950	30668	35.2	65.2	(Bosma *et al.* 2011)
Pig	China	PIG	Live weight	8400	44700	97.5	66.3	This study
Pig	Germany		Edible yield	3220	19500	57.1	23.3	(Reckmann *et al.* 2013)
Pig	UK	GAP (Good Agriculture Practice)	Live weight	2300	15900	43.5	20.8	(Basset-Mens & van der Werf 2005)

Note: GWP=global warming potential, CED=cumulative energy demand, AP=acidification potential, EP=eutrophication potential, CIQ=non-integrated CIQ pond tilapia farms, TP=non-integrated non-CIQ pond tilapia farms, TIML=medium and large-scale integrated tilapia farms with pig farming excluded, TIS=small-scale integrated tilapia farms with pig farming excluded, PIG=pig farms

7.4.2. Uncertainty, contribution and sensitivity

Uncertainty analysis shows the coefficients of variation (CVs) vary from a moderate 25%-68% of GWP, to very high 50%-137% of CED. The wide range and high value of CVs shows the nature of highly diverse farming systems, which is to a large extent subject to the vagaries of local natural conditions.

Contribution analysis shows feed input, electricity and farming practice were the major contributors for all impact categories. Sensitivity analysis confirmed the different electricity sources, different feed efficiency and fishmeal levels in feed, all brought significant changes for different impact categories. The feed was the biggest source of environmental impacts in all impact categories; poorer feed efficiency inevitably causes more environmental impacts. Although 5% higher feed efficiency only affected a few environmental impact categories, 10% higher feed efficiency caused a significantly lower impact in most impact categories. This could explain the lower eFCR of small integrated farms and correspondingly lower environmental impacts. At the same time, feed is the most important cost item for aquaculture farms (Shang *et al.* 1998) and lower eFCRs not only leads to reduced environmental impacts but also brings broader sustainability.

Besides feed efficiency, the fishmeal level in feed also brought significant changes in many impact categories, due to high environmental impacts of fishmeal production (Pelletier *et al.* 2009). However, reduced fishmeal content in the feed may cause increase in FCR, and the resultant overall environmental impacts need further study. While reducing feed inputs is not easy, reducing fishmeal level in the feed could be a shortcut to reduce overall environmental impacts.

7.4.3. Future of IAAS

IAAS are dynamic over time and are subject to economic and environmental change (Prein 2002). IAAS in China have gradually become intensified with more pellet feed inputs, and such integrated systems have evolved into more industrialized and separate systems for both fish and livestock in recent years (Edwards 2011b; Edwards 2009; Li 2003; Wong *et al.* 2004), together with a trend towards diversification of farmed fish into the production of high-value luxury species (Prein 2002). For example, now most tilapia produced in China for export is raised in non-integrated polycultures in pellet-fed aerated ponds (Edwards 2011a).

The principle of traditional aquaculture practice in China still can promote environmentally and socially sustainable, such as IAAS and polyculture. Field survey shows rice yield is similar between rice fish IAAS and rice monoculture, but rice fish culture requires 68% less pesticide and 24% less chemical fertilizer for rice farming (Xie *et al.* 2011). The polyculture of high value species with 'service fish' such as silver carp to feed on the phytoplankton produced by fish metabolic waste has multiple benefits (Edwards 2008; Edwards 2011a; Edwards 2010).

The IAAS may still be useful during nursery stages, feeding thereby being delayed until fish reach a larger body size (100 grams) to utilize food organisms produced from natural production in pond ecosystems fertilized by feed waste or organic fertilizer and reduce feed cost (Diana *et al.* 2013; Edwards 2011a). The integration of aquaculture with other food producing sectors or ecosystems, such as IAA, IMTA and ranching, has an integral role to play in the future of the aquaculture industry (Bostock *et al.* 2010)

This study shows small-scale integrated farms performed well, having lower eFCR and environmental impacts than larger farms and non-integrated farms. In China, government only requires mandatory waste treatment in large-scale livestock and poultry farms (e.g. farms with more than 300 pigs), but no such regulation for the dominating small-scale farms (MOE 2009). Livestock farming remains dominated by small-scale farms; for example, more than 98% of pig farms were small-scale (<100 pigs) in 2010, but they accounted for less than half of total production (48.% of national annual production). Average yields were less than 8 pigs per farm (Liu *et al.* 2011; NDRC 2013). Pig manure treatment and utilization in large-scale pig farms was proven viable due to economies of scale (Lin *et al.* 2010). However, manure collection from scattered and small-scale pig farms is economically impractical and survey shows the cumulative effect of untreated manure discharged from these farms caused high environmental impacts (Peng *et al.* 2010). In general, IAAS is still valuable and meaningful to reduce overall environmental impacts in small-scale farms.

Integrated aquaculture systems were seen as suitable for small-scale farms who usually are nutrient-limited (Prein 2002). This study suggested there was a 'scale effect' as it found medium and large-scale farms had similar eFCR and total environmental impacts to non-integrated farming, along with intensive farming practice. As none of the systems was nutrient limited, the main benefit from the small-scale systems was that pig waste appeared be more efficiently managed and converted to natural feed allowing greater sparing of fish feed. In larger farms poorer manure management could have had adverse impacts through high eutrophication levels and other negative impacts.

7.4.4. Lower impact of aquaculture industry

Comparing production and energy efficiencies of aquaculture versus other animal protein production alternatives can address in a more rigorous manner the available choices for resource use and production systems (Costa-Pierce *et al.* 2011). Many LCA studies suggest that farmed seafood is relatively efficient compared to most livestock production and that commodities such as tilapias and shrimps that can derive part of their food from natural sources may have a comparative advantage (e.g. Pelletier *et al.* 2009). This study also shows tilapia farming performed much better than pig farming in most of environmental impact categories.

According to National Development and Reform Commission (NDRC)'s publications, the China's total CO_2 equivalent weight emission was 2,666 mmt and 5,976 mmt in 1994 and 2005 respectively (NDRC 2004; NDRC 2013b). Of the 5,976 mmt CO_2 emission in 2005, agriculture accounted for 10.97% (819.97 mmt), which mainly came from greenhouse gases such as NO_2 and CH_4 from livestock farming and rice farming (NDRC 2013b). The total CO_2 emissions from China's aquaculture industry was reported at 9.89 mmt in 2008, which was calculated from energy consumption survey and statistical data (Liu & Che, 2010). The CO_2 emission from aquaculture industry is very low compared with the whole national CO_2 emission and CO_2 emission from agriculture.

The first national pollution census bulletin shows the total agricultural source pollution discharge as follows: Chemical Oxygen Demand (COD) 13.24 mmt, total nitrogen 2704.6 thousand mt, and total phosphorous 284.7 thousand mt. Although aquaculture accounted for more than 11% agriculture GDP, it only accounts for 5% of the total combined agricultural pollution in these categories (NBSC 2010).

8. CHAPTER 8: Understanding shrimp and tilapia farmer motivations and impediments to improved record keeping in southern China

8.1. Introduction

Farm record-keeping is believed to be an important farm management tool (Jeyabalan 2010; Silver 2006; Smith *et al.* 2005; Viloria Carrillo 2010; Yami 2009), and required by legislation, food safety standard, traceability and third party certifications (ASC 2012; Baier 2011; BAP 2008; European Commission 2002; FAO 2009a; GLOBALG.A.P. 2013; MOA 2006c; Taylor 2001). Existing studies on farm record-keeping have mainly focused on crop and livestock farming (Carrillo 2010; Devonish *et al.* 2000; Estrin 2010; Tham-Agyekum *et al.* 2010; Viloria Engler & Toledo 2010). This section tries to get a better understanding of recording keeping in aquaculture farms in China using an action research (AR) approach (SEAT 2010; Waley 2010).

8.1.1. Traceability

Food safety is now universally recognised as a public health priority (OIE Animal Production Food Safety Working Group 2006). More educated and highly aware consumers demand more information from food supply chain (Sallabi *et al.* 2011). Ensuring food safety has been the primary driver, though environmental and social criteria have become increasingly important – particularly in third party-standards (e.g. GLOBALGAP, ASC, ACC). Animal welfare is a further emergent criterion (Animal Welfare Approved 2013). These (third party) standards have been driven by ethical supply chain management (ESCM) requirements imposed on consumer-facing value-chain segments who must manage the risk to their brand reputation. Agricultural products may have characteristics that are not easily distinguished by consumers, such as being GMO or organic or being subject to different types of processing. Record-keeping and traceability is necessary to verify these attributes (Golan *et al.* 2004a; Moe 1998).

Along with food safety concerns, food traceability has become very important globally in recent years (Storøy *et al.* 2013). According to Regulation EC (European Commission) No. 178/2002, the definition of traceability is: ''*ability to trace and follow a food, feed, food-producing animal or substance intended to be, or expected to be incorporated into a food or feed, through all stages of production, processing and distribution*" (European Commission 2002). Traceability systems have the potential to help industry achieving optimal benefits from quality control, production control and for fulfilling consumer demands (Moe 1998), and ensure food safety and quality and reductions in the costs associated with recalls (Regattieri *et al.* 2007). The drivers and benefits of food traceability have been identified as legislation, food safety, quality, sustainability, welfare, certification, competitive advantages, chain communication, terrorist threats, and production optimization (Karlsen 2011). It was believed that all enterprises in global food supply value chain would be obliged to adopt traceability or find it difficult to stay in business (Smith *et al.* 2005).

Traceability systems require systematic recording and documentation along the supply chain (Storøy *et al.* 2013), in a word, ''*traceability is a series of recorded identifications*'' (Golan *et al*. 2004a; Smith *et al.* 2005). Record-keeping is one of the key procedures in the establishment of a traceability system (ISO 2007), and can assures traceability through all or parts of the product life-cycle (Smith *et al.* 2005).

A traceability system for tracking every input and process to satisfy every objective would be enormous and very costly (Golan *et al.* 2004a). Information exchange (especially electronic exchange) in the supply chain is very time-consuming or difficult (Storøy *et al.* 2013). Practically, for most traceability systems information is kept internally and only a limited amount moves externally (Karlsen 2011; Moe 1998). Thus, traceability systems have different characteristics in terms of breadth (the amount of information collected), depth (how far back or forward the system tracks) and precision (degree of assurance or product movement or characteristics) (Golan *et al.* 2004a), and can be divided into chain traceability (track through the whole, or part, of a production chain) and internal traceability (track in one of the steps in the chain, for example, the production step) (Moe 1998). Analysis of different levels of traceability systems for cattle and beef in the EU, Australia, Brazil, Japan, Canada, US shows different requirements for traceability in terms of depth, breadth and precision, mandatory/voluntary, end at retail level/farm level/animal level (Smith *et al.* 2005). Traceability can be divided into categories such as country of origin; retail; processor; and farm-to-retail identity (McKean 2001). Traceability also can be classified as one of two models: a generic, low-warranty traceability procedure which is used mainly for chain traceability, or a specific, high-warranty traceability procedure link with internal traceability (Lavelli 2013).

The food safety controlling tools such as the Codes of Hygienic Practice and the Hazard Analysis and Critical Control Point system (HACCP), have proven their effectiveness in food processing and distribution sectors but are seldom used in the farming sector (OIE Animal Production Food Safety Working Group 2006). Even in the EU market, most traceability systems are low-warranty chain traceability, and only beef products use high-warranty traceability which involves internal traceability at the farm level (Lavelli 2013). However, a fully traceable supply chain requires both chain traceability and internal traceability (Thakur & Hurburgh 2009; Storøy *et al.* 2013; Porto *et al.*

2011). The EU has also started to address internal traceability in its regulation (EUROPEAN-COMMISSION 2012). Internal record-keeping and traceability system can identify the true source of a problem of contamination of products of animal origin and implement measures to eliminate, and can control food safety risks in the primary production sector (OIE Animal Production Food Safety Working Group 2006).

Farmed seafood traceability systems have been widely implemented in developed countries. For example, the traceability system of farmed Norway salmon has established a data recording system that can record salmon farming process from eggs and fry produced data at the hatchery sector to date of stocking, farm licence number, farm site, cage number, feeding regimes, vaccination and medical treatment at farm sector, and date of slaughter, weight at slaughter in processor sector (Håstein *et al.* 2001).

Traceability systems in China have been built for export value chains through CIQ registration system. However, no similar traceability system for aquatic products is in place for domestic market. Although several food traceability systems have been trialled in China, it has not been implemented on a national scale (Xu *et al.* 2012). There were experiments in some important fisheries provinces to build aquatic product traceability systems but such systems are still not fully functional (Wang *et al.* 2012). It is reported that only a small fraction of China's agriculture farms participate in export trade; the CIQ registration system excludes most (small-scale) farms from export value chains (Gale & Buzby 2009).

8.1.2. Record-keeping

Record-keeping can be defined as "*information that has been systematically and carefully collected* *and appropriately stored for intended use*" (Okeke 2012) or "*keeping, filing, categorizing and maintaining farm financial and production information by a variety of methods, from a basic hand record-keeping method to an elaborate computerized system*" (Gerloff 2012) or "*keeping physical information, financial information, or both, whole-farm information or records related to a specific aspect of the farm*" (Viloria Carrillo, 2010). Farm records can be classified as resource inventories, production records, financial records and supplementary records (Tham-Agyekum *et al.* 2010). Farm records should include production data such as start/stocking date, animal population, animal movements, feeding regimes, chemical use, disease and mortalities (FAO 2009a). Farm level record-keeping system is the foundation of a traceability system (Li *et al.* 2010). A stable, accessible record system is essential for retrospective analysis (Moe 1998).

Beyond external regulatory requirements, record-keeping is a modern farm management tool, which can help in the effective farm management and making informed decisions (Chagunda *et al.* 2006; Devonish *et al.* 2000; Engler & Toledo 2010; Gerloff 2012; Jeyabalan 2010; Muhammad *et al.* 2004; Silver 2006; Steinberger *et al.* 2006; Yami 2009). Record-keeping has a positive effect on farm economic results (Viloria Carrillo 2010). For example, record-keeping has been demonstrated to effectively increase milk fat percentages and reduce bacterial scores (Rhone *et al.* 2008). Milk production can be substantially improved by establishing simple, accurate, understandable and easy to keep recording systems (Chagunda *et al.* 2006). Keeping records can help farmers to organise their observations, recognize patterns in relationships across the farm, solve problems, and develop sound plans (Baier 2011). Record-keeping also promote the idea of 'farming as a business', which can help farmers identify market opportunities for their products and gain insight into the costs and margins involved in the value chain (Wegner & Zwart 2011). Record-keeping make any farmer think of their farm as a business, and that good care and management actually affect the production and profitability of the farm (Biovision Foundation 2013). In some contexts it's also been important in getting loans, paying taxes or getting a tax return (Gerloff 2012; Devonish *et al.* 2000). As for aquaculture farms, keeping good records is part of important management system (FAO 1998).

Farm record function and purpose was classified into internal drivers and external drivers, according to farmer's motivation to keep records (Table 8.1). Some purposes may overlap with each other, such as food safety and market gaining, and certification and animal welfare.

8.1.3. Adoption

The farmer can either keep records by themselves or outsource data entry and analysis to an outsider such as a financial consultant (Gloy *et al.* 2002). Farmers often don't like record-keeping and consider it as a burden (Taylor 2001); their decisions tend to be based on estimates and guesses (Tham-Agyekum *et al.* 2010). Early studies show many farmers actually don't keep any records (Akcaoz *et al.* 2009; Devonish *et al.* 2000; Ragoonath-Devonish 2005; Viloria Carrillo 2010), especially small-scale farmers (Jeyabalan 2010; Minae *et al.* 2003; Muhammad *et al.* 2004). The records most likely to be kept by farmers were sales and expenditure (Ragoonath-Devonish 2005).

Table 8.1 Internal drivers and external drivers of farm record-keeping

Motivation	**Purpose**	**Details/examples**	**Reference**
Internal drivers	Farm management	Decision making	(Gerloff 2012; Jeyabalan 2010; Schlender 1991; Wolf *et al.* 2011)
		Finance accounting	(Batte 1990; Gerloff 2012)
		Planning	(FAO 1998)
		Identify problems	(FAO 2009a)
	Food safety/HACCP	Risk management	(Gall & Rivara 2000; Reilly & Käferstein 1997; Taylor 2001)
	Efficiency improvement	Benchmark farm performance	(Chagunda *et al.* 2006; Gietema 2006; Moran 2009; Wolf *et al.* 2011)
		Input and labour efficiency	(Biovision Foundation 2013)
	Market gaining	Release information to consumers	(Chen & Huang 2013)
	Market trends forecast	Time of buying and selling	(Eisgruber 1975)
External drivers	Legislation/regulation	In general	(FAO 2009a; MOA 2006c)
		Tax reporting	(Chembezi 2002; Gerloff 2012; Schlender 1991)
		Control of use veterinary chemicals	(Department of Environment and Primary Industries 2007; FDA 1998; Stefan 1997)
	Institutional requirements		(Gerloff 2012)
	Traceability		(European Commission 2002)
	Certification	GLOBALGAP, ASC, ACC, organic food	(ASC 2012; Baier 2011; BAP 2008; GLOBALG.A.P. 2013)
	Animal welfare		(Animal Welfare Approved 2013; Black & Glatz 2011; Berrill *et al.* 2012)
	Obtaining credit	Get loan from bank	(Chembezi 2002; Devonish *et al.* 2000; Tham-Agyekum *et al.* 2010)
	Farm insurance		(Anrooy 2004; Carkner 2001)
	Government subsidy		(Tham-Agyekum *et al.* 2010)
	Government extension/help		(Tham-Agyekum *et al.* 2010)
	Public applied research	Policy development	(Tham-Agyekum *et al.* 2010; Wolf *et al.* 2011)

8.1.4. Record analysis

Farm records in themselves are just raw data and not useful information (Viloria Carrillo 2010); they need to be analysed to produce valuable information and help with better management decisions (Schlender 1991). Record analysis will help farmers understand where the income was produced, strengths and/or weaknesses of the farm business, returns for labour and management, trends in net worth and the operation's production efficiency (Arzeno 2004), and guide farmers to take actions or make decisions for future planning (Jeyabalan 2010).

Farm records have many forms, from hand written to computerised record-keeping (accounting) systems. Hand written record-keeping systems are cheap and easy to use, and have been adopted by many small-scale dairy farms (Jeyabalan 2010); it's more time consuming and not as accurate as a computerised record-keeping system. More importantly, a computerised record-keeping system can be a powerful analysis tool in processing large amounts historical data and hand writing systems are limited in the extent of analysis possible (Gerloff 2012; Moe 1998). One study showed farmers who used a computerized record-keeping system used more time to analysis their records and turn records into profitable information than farmers who used hand written system (Gloy *et al.* 2002). A computerized record-keeping system also makes it realistic to develop traceability systems with very detailed information about both the product and its processing history (Moe 1998). Farm computer and computerised record-keeping was found to be popular in the US, where 44% of farms are equipped with a computer and 75% of them used computers to keep farm records in 2003 (Batte 2005). Although some record-keeping software is already available, small-scale farmers are unlikely to use them due to the expense and the complexity of the programs, and their level of computer literacy (Jeyabalan 2010). The research found that without help from modern information technology, most farmers who kept records didn't efficiently analyse and utilize it (Viloria Carrillo 2010), and found no difference in technical and economic efficiency between record keepers and non-record keepers because farmers only measured profitability rather than tried to enhance it (Ragoonath-Devonish 2005). Hand written systems make analysis difficult, make finding important data, analysing and using it to make any decisions difficult. Hence, small-scale farmers usually make less effort to analyse and to use results for further action (Jeyabalan 2010).

8.1.5. Research Background

Aquaculture growth is strongly influenced by markets, trade and consumption preferences with clear demands for the production of safe and quality products (Subasinghe *et al.* 2009). Developed countries are the biggest seafood buyers on the international market and accounted for 76% of world seafood import in 2010, in which around half originated from developing countries (FAO 2012c). Trade in seafood to developed countries imposes greater quality control demands on aquaculture farmers in developing countries - including a requirement for systematic record-keeping linked to product traceability. By January 2005, all seafood exports to the EU market were required to implement a traceability system to comply with the requirements of Regulation (EU) No 178/2002 of the European Parliament and the Council (Dillon & Derrick 2004)

The Chinese government has made efforts on food safety issues and a mandatory domestic (CIQ) registration schemes imposes minimum (food safety) standards on farms wishing to export produce (China Entry-Exit Inspection and Quarantine Bureau 2004). For the domestic market, the pollution-free agriculture and animal husbandry products registration schemes also aim at improving food-safety. In recent years, several food traceability systems have been trialled in China (Xu *et al.* 2012). However, inefficient record-keeping of small-scale and scattered farms has prevented the wide application of traceability systems in China (Li *et al.* 2010).

In the baseline studies, many farmers were found to keep few or no records. Only 33% (n = 407) of farmers reported record-keeping, including 26.5% (n = 200) shrimp farmers and 40.5% (n = 207) of tilapia farmers. The most frequently kept record was feed input, and chemical use, growth, water quality, and mortality. Record-keeping was therefore identified as an area of further research within the SEAT project.

8.1.6. Objectives

To understand trends in record-keeping practice, motivation and capacity - for different farm types (species, system and farm-scale) and potential for improvements.

8.1.7. Research hypothesis

Incentives for record-keeping are likely to be positively correlated with farm-scale for the following reasons:

a) Record-keeping imposes higher marginal costs on smaller relative to larger-scale enterprises

b) Smaller farms have lower capacity for record-keeping e.g. due to educational status, less labour specialization etc.

c) Smaller farms with fewer ponds and less complex production cycles have less need for detailed pond-level recording for their profit and loss calculations/estimation.

d) Larger farms producing for export are more likely to have recording requirements imposed on them by buyers/processors.

Smaller farms are unlikely to adopt improved record-keeping procedures without external regulatory pressure. Under current conditions adoptable systems must be simple and concerned primarily with improved profit-and loss accounting – particularly related to feed use.

8.1.8. Research questions

a) How do record-keeping practices vary between, farming systems (tilapia and shrimp), farm-scale and market orientation (domestic and export)?

b) What are the motivations for farmers to keep different types of records - or not?

c) What other factors affect the capacity of farmers to keep records (age, gender, education status, former employment and training etc)?

d) How can record-keeping performance be enhanced to improve economic, social and environmental performance?

8.2. Methods

The methods used were modified from AR framework developed by the SEAT project (Waley 2010). It was an iterative five-stage research framework: diagnosis, action planning, taking action, monitoring and evaluation, and assess learning.

8.2.1. Diagnosis

The diagnosis stage was part of the SEAT integrated baseline survey with shrimp and tilapia farms conducted in Guangdong and Hainan province in China in 2010 (see Chapter 5). One question asked in the survey was “What written records do you regularly keep, tick only those kept over the last year, otherwise leave blank – add additional categories as necessary” and record type, including Feed, Mortality, Growth, Water quality, and Chemical use.

8.2.2. Action planning and implementation

Based on the survey result, an action research plan was made. The first step was developing a ‘one-size-fits-all’ pro-forma, Chinese version of a record-keeping book based on a system originally developed by another extension project[11]. The record-keeping book was revised to make it appropriate for tilapia and shrimp farming including the components : 1, calendars; 2 farm information; 3 infrastructure; 4 Farming schedule; 5 feed, chemical, equipment purchases; 6 chemical using; 7 farming record (feed, water quality, etc.); 8 harvest; 9 annual summary table; 10 appendix (Appendix 6).

Copies of record-keeping books were printed and sent by post to all farmers who participated in the SEAT baseline survey in October 2012.

8.2.3. Monitoring and evaluation and assess learning

A sequential mixed methods approach was applied consisting of three phases: a. qualitative (piloting) – b. systematic survey and – c. in-depth qualitative case studies.

a) Piloting work was conducted in March 2013 to develop a short (4 page) pre-coded systematic survey questionnaire (Appendix 7).
b) A systematic survey conducted by telephone in April 2013 with 407 farmers involved in the previous SEAT baseline survey. Each phone call survey lasted around 15 min, all results were kept in printed survey forms before keying in to an Excel database.

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11 Prof. Wu Wang, 2012, per comm, Ministry of Agriculture Fisheries Science and Technology Enter Farmer Households Programs 2005-2012, Shanghai Ocean University

c) Based on the outcomes of (b) - a sub-set of cases was selected for final face-to-face in-depth semi-structured interview to provide explanatory power for observed trends in June 2013.

In addition, the interim results were validated at a regional workshop in Maoming on the 18 to 19th of April 2013, a summary of phase b results (15 min ppt) was presented leading to a canvassing of the opinions of a range of value-chain stakeholders, finishing with a one-page questionnaire survey (Appendix 8) conducted with participants.

8.2.4. Data management and analysis

Data management and analysis methods used are given in chapter 5.

Moreover, bivariate correlation tests were conducted to check correlations between number of records and farm productivity and efficiency.

8.3. Result

8.3.1. Action taken and piloting

Farm record-keeping was mainly related to product traceability. A mandatory domestic (CIQ) registration scheme imposes minimum (food safety) standards on farms wishing to export produce, which requires farm record-keeping. Currently no such system is in place for producing exclusively for the domestic market. Middlemen and processors take samples away for residue testing before sourcing fish and shrimp for export. ‘Domestic-middlemen’ conduct (only) spot checks on size variation, fish-condition, intestinal feed-content and occasionally off-flavour. Little evidence was found of any record-keeping linked to social or environmental performance (e.g. waste disposal, disease management etc.). Only one BAP certified large-scale CIQ shrimp farm was certified and reported the necessity to fulfil certain social and environmental requirements.

All farmers are subject to national statutes, which may impose record-keeping burdens now or in the future e.g. linked to taxation, environmental performance, domestic food safety etc. In Guangdong the District Fisheries Technical Extension Stations are required to implement a farm-level registration and linked traceability scheme during 2013-2015 (three years) for all farms. This will impose mandatory reporting requirements on all producers mainly for domestic market.

Preliminary action-research, which tested a ‘one-size-fits-all’ pro-forma recording system for tilapia and shrimp farms at different scales and market orientations – was unsuccessful. Most small and medium farmers found it too complex and unsuited to their needs – whilst larger farmers already had their own pro-forma systems.

Piloting work indicated small and medium farms either kept no records or used A5 notebooks -to record feed inputs (mainly) for profit and loss calculation or pre-harvest forecasting based on expected FCRs. A few used simple pro-forma formats (month to view and one book per pond) provided by feed companies, which allowed some feed company ‘technical advisors’ to collect feed use data for their own purposes. Very few farms used recorded data for comparative analytical purposes, either between ponds or years – relying instead on more instinctive trial and error, ‘learning by observation’. One farm reported using a computer for data storage, but no farms were found to use computers for analytical purposes.

8.3.2. Systematic survey response

One hundred and fifty one (37.1%) farms (70 shrimp, 80 tilapia) were interviewed in the piloting (n = 19) and telephone survey (n = 132) among the 407 farms in the baseline survey. The reasons for non-response were mainly related to farmers not being contactable by phone, e.g. no phone number, wrong number and phone number out of service. A few farms had stopped farming or could not speak fluent Mandarin, and some didn't want to respond (Figure 8.1).

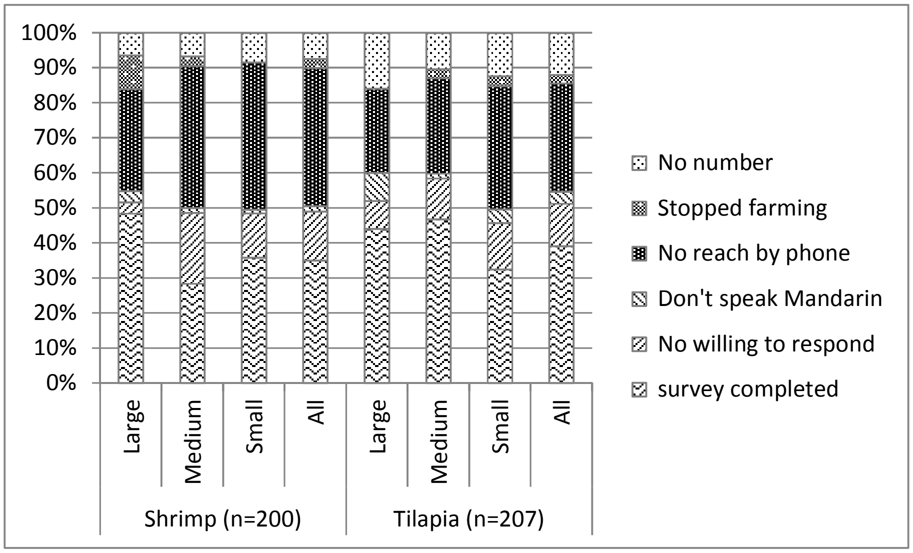

Figure 8.1 Survey response rate and the reasons for non-response

8.3.3. Farm and interviewee profiles

High-level shrimp farms accounted for 60% of the total shrimp farms surveyed, followed by 36% low-level shrimp monoculture farms and 14% low-level shrimp polyculture farms. Non-integrated pond tilapia farms accounted for half the surveyed tilapia farms, followed by 45% integrated tilapia farms and 5% reservoir farms. Small-scale shrimp and tilapia farms outnumbered medium and large-scale farms, and non-CIQ farms accounted for 85% of all farms. All shrimp farms were located in Zhanjiang, while 65% tilapia farms in Maoming and 35% in Hainan.

Farm and interviewee profiles were analysed and are presented in Figure 8.2 and Figure 8.3.

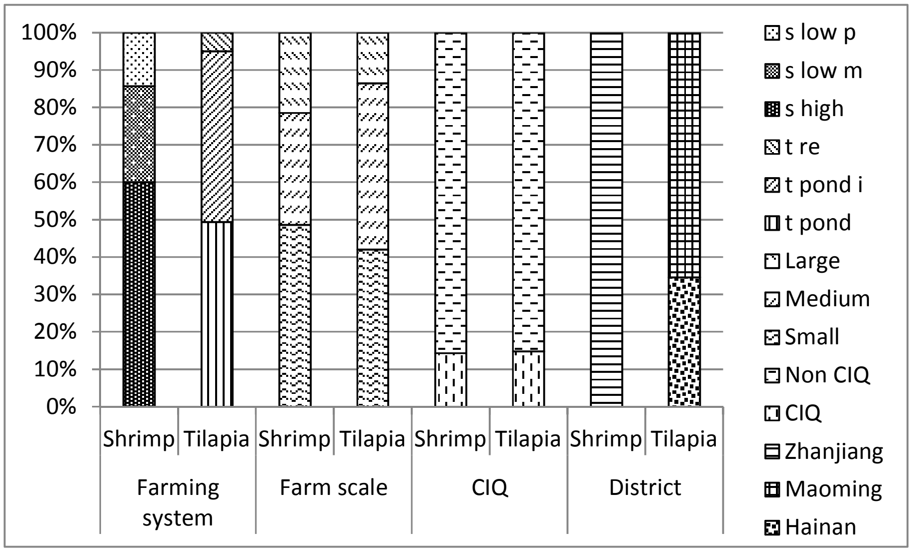

Figure 8.2 Farm profiles of shrimp and tilapia farms

(s high= High-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

Most of the interviewees were farm owners, with less than 20% being employees (worker and manager/technician). The majority of interviewees were male, within an age range of 24 to 63. Most of them had at least five years' experience and most had middle or high school education level (Figure 8.3).

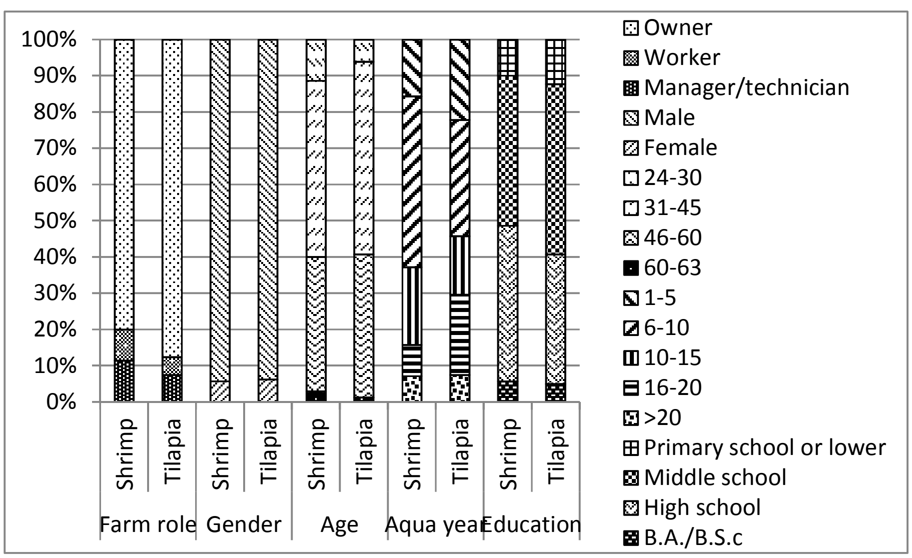

Figure 8.3 Interviewee profiles of shrimp and tilapia farms

8.3.4. SEAT record-keeping book

Thirty per cent (n = 46) farmers reported that they had received the SEAT book, and only one of them started to use it and seven reported they planned to use it. Three farmers reported the feed section was useful and three thought the whole record-keeping book was useful. The main reason for the low delivery rate included the remote farm location (especially for reservoir tilapia farms), the lack of a clear postal address, farmers not being local residents and a complicated administrative system such as confusing names of administrative villages and nature villages[12].

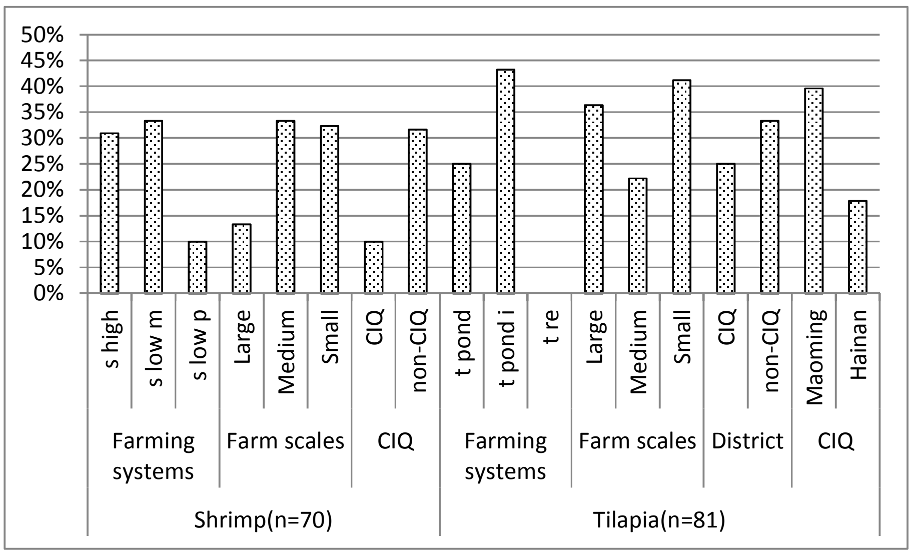

Figure 8.4 Proportion of farms received SEAT record-keeping book

(s high= High-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

8.3.5. Record-keeping adoption rate

More than 60% (64.3%; n = 45) of shrimp farms reported they kept some type of farm records. There was no difference between farming systems (P>0.05), but fewer small and medium-scale

[12] The natural village is a single ecological unit integrated by economic production and social cooperation. The administrative village is a political unit, so defined by the state. The administrative village may coincide with the natural village or it may consist of a grouping of several natural villages (Schurmann 1968).

farms kept records than large-scale farms (P<0.05) and less non-CIQ farms keep records than CIQ farms (P<0.05).

More than 65% (65.4%; n = 53) of tilapia farms reported they kept farm records. Less non-integrated tilapia farms pond and tilapia integrated pond-based farms kept records than reservoir farms (P<0.01) and less small and medium-scale farms kept records than large-scale farms (P<0.01). Fewer non- CIQ farms than CIQ farms (P<0.01) had evidence of record-keeping. No difference was found between tilapia farms in Guangdong and Hainan (P>0.05).

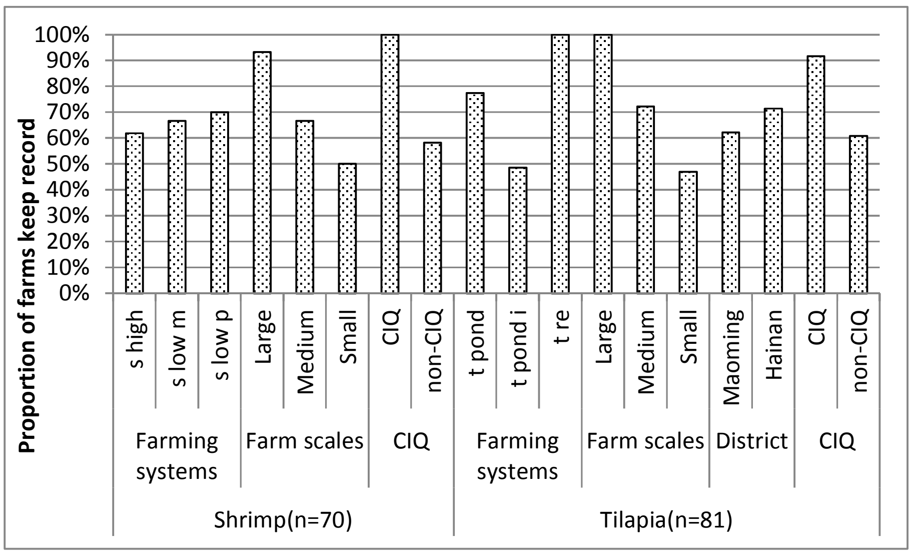

Figure 8.5 Proportion of farms keeping records.

(s high= High-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

8.3.6. Record types

Feed input was the most frequent record type kept by both shrimp and tilapia farmers, followed by pharmaceuticals for shrimp farmers and stocking numbers and date by tilapia farmers (Figure 8.6).

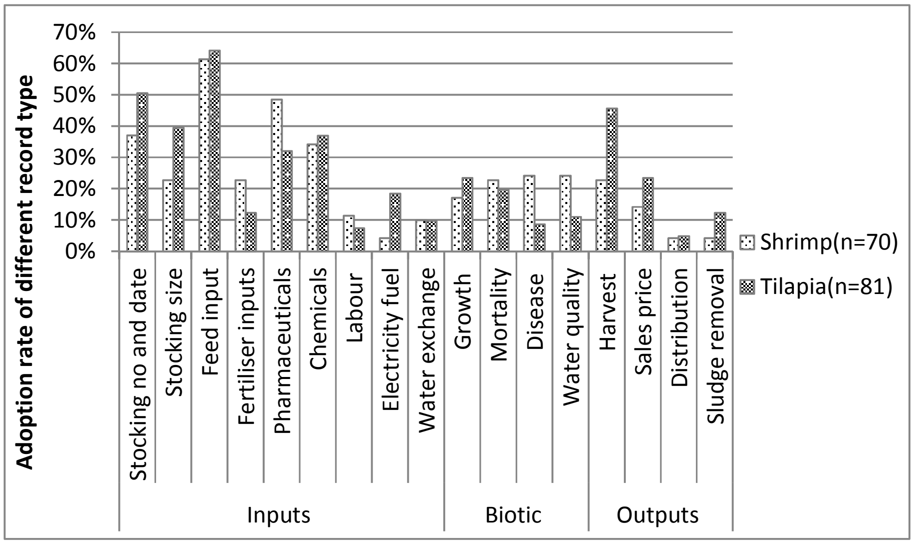

Figure 8.6 Adoption rate of different record types kept by shrimp and tilapia farms.

8.3.7. Total number of records types kept by farmers

No significant differences in productivity and efficiency were found between different farming systems for both shrimp and tilapia on the number of record types kept by farmers (P>0.05). Large shrimp farms kept more records than small-scale shrimp farms, and large tilapia farms kept more records than both small and medium-scale farms (P<0.05). Both shrimp and CIQ tilapia farms had more records than non-CIQ farms (P<0.05). There was no difference between tilapia farms in Hainan and Maoming (P>0.05) (Figure 8.7).

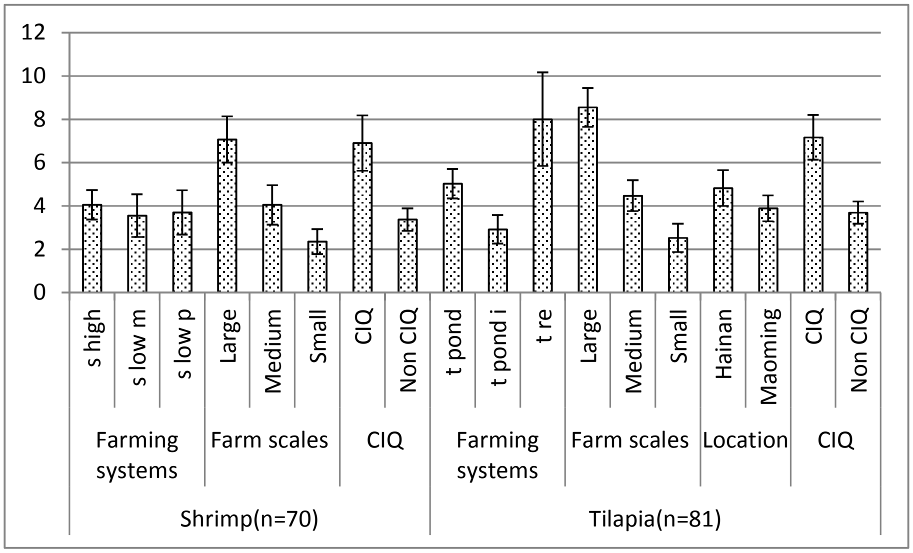

Figure 8.7 Number of record types kept by different farmers

(s high= High-level shrimp farms, s low m= low-level shrimp monoculture farms, s low p = low-level shrimp polyculture farms, t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

8.3.8. Record-keeping and productivity

No significant differences in the productivity and efficiency were found between shrimp record keepers and non-record keepers, although small differences existed (Figure 8.8).

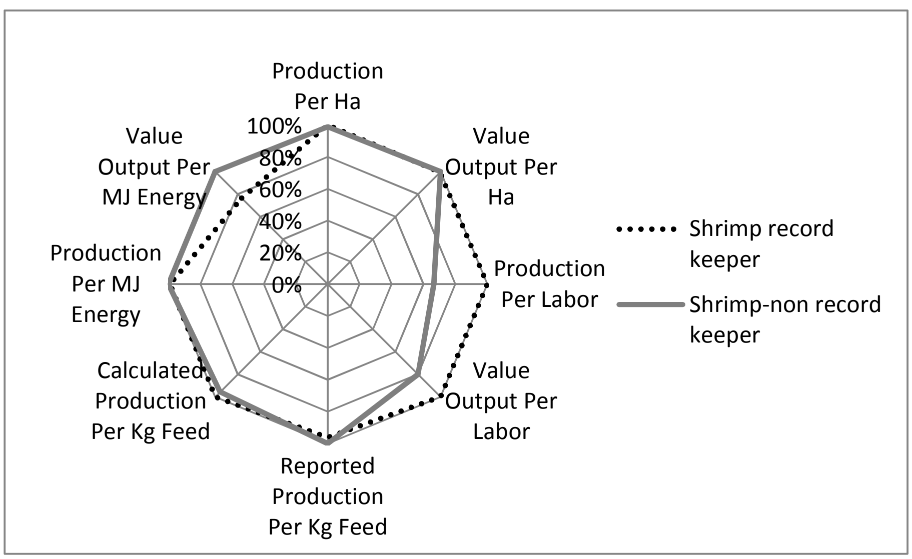

Figure 8.8 AMOEBA analysis of productivity and efficiency of between shrimp record keeper and non-record keeper

Bivariate correlations test also showed no significant correlations between the number of record types and productivity and efficiency indicators (P>0.05).

Tilapia record keepers had significantly higher labour productivity in both production and value output terms than non-record keepers (P<0.01), however, the energy efficiency was lower (P<0.05). No significant difference in land productivity and feed efficiency was found (P>0.05) (Figure 8.9).

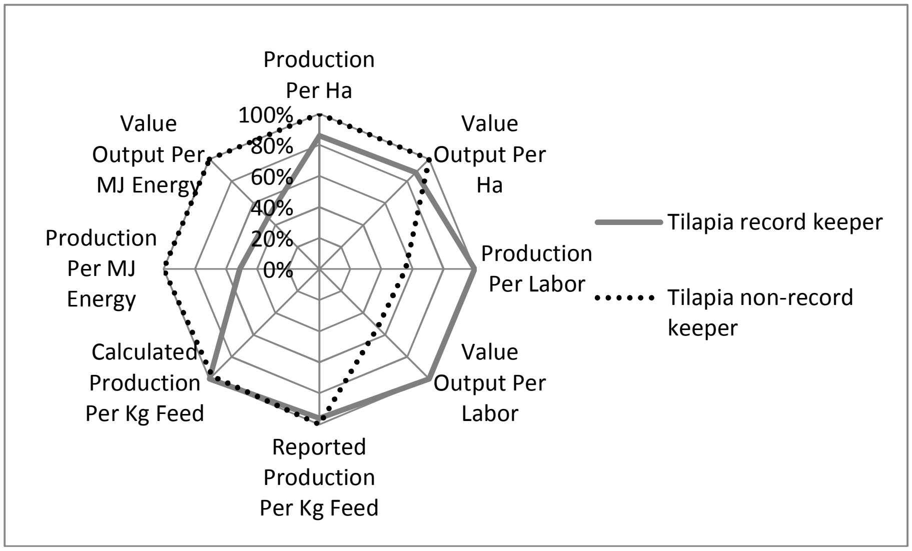

Figure 8.9 AMOEBA analysis of productivity and efficiency of between tilapia record keeper and non-record keeper

Bivariate correlations test also shows significant correlations between the number of record types and productivity and labour productivity in both production term and value output term (P<0.01), and between the number of record types and energy efficiency (P<0.05). Keeping more records seemed to result in higher labour productivity but lower energy efficiency.

8.3.9. Record-keeping details of shrimp farms

There was almost no difference for different types of shrimp farming systems, the only difference was high-level shrimp farms kept more records for growth sampling than low-level shrimp farms (P<0.05).

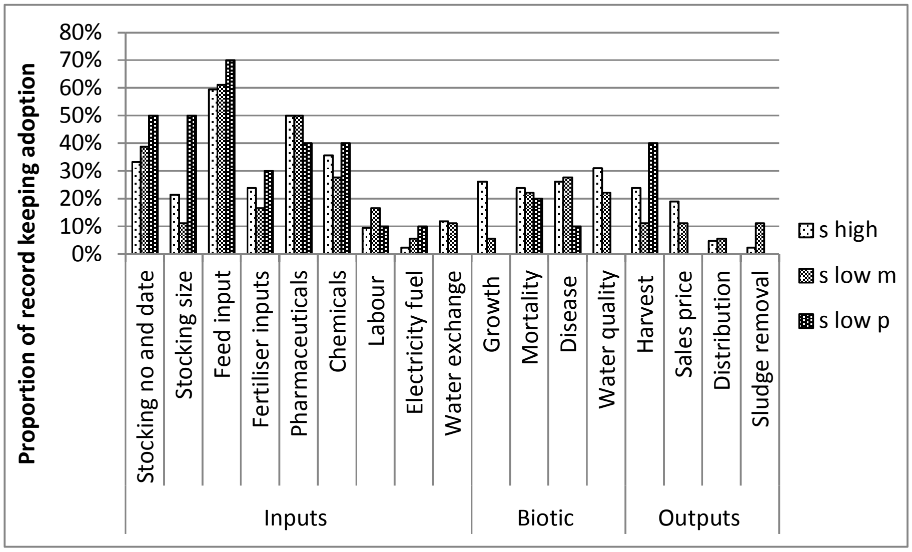

Figure 8.10 Adoption rate of detailed farm record-keeping by systems, farm scale and CIQ registries of shrimp farms

(s high= High-level shrimp farms, s low m= low-level shrimp monoculture farms, and s low p = low-level shrimp polyculture farms

Significant differences were found in records between different sized shrimp farms; large-scale shrimp farms kept more records on stocking number and date, stocking size, feed input, labour salary and time, growth, final harvest and sales price than small and medium farms (P<0.05).

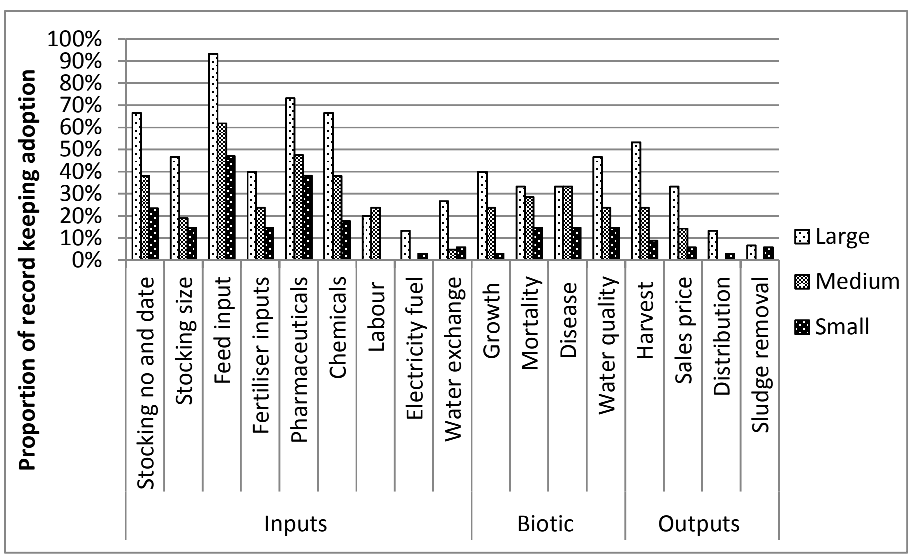

Figure 8.11 Adoption rate of detailed farm record-keeping by shrimp farm size

CIQ farms also kept more records than non-CIQ farms on feed input, chemical use, growth sample weight, harvest, sales price and distribution (P<0.05).

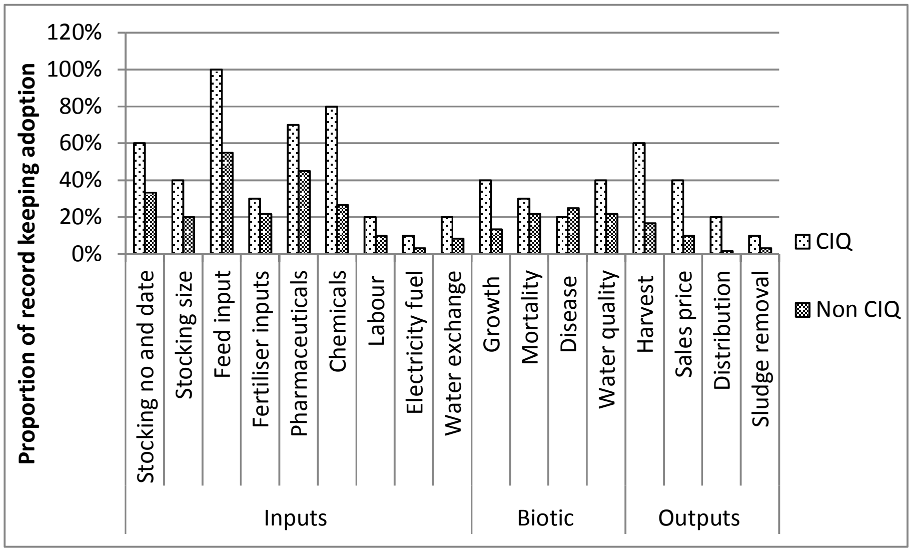

Figure 8.12 Adoption rate of detailed farm record-keeping details of CIQ and non-CIQ shrimp farms

8.3.10. Record-keeping details of tilapia farms

Reservoir tilapia farms kept more records than tilapia pond –based farms for stocking number and date, feed input, labour salary, electricity and fuel, water exchange and mortality (P<0.05).

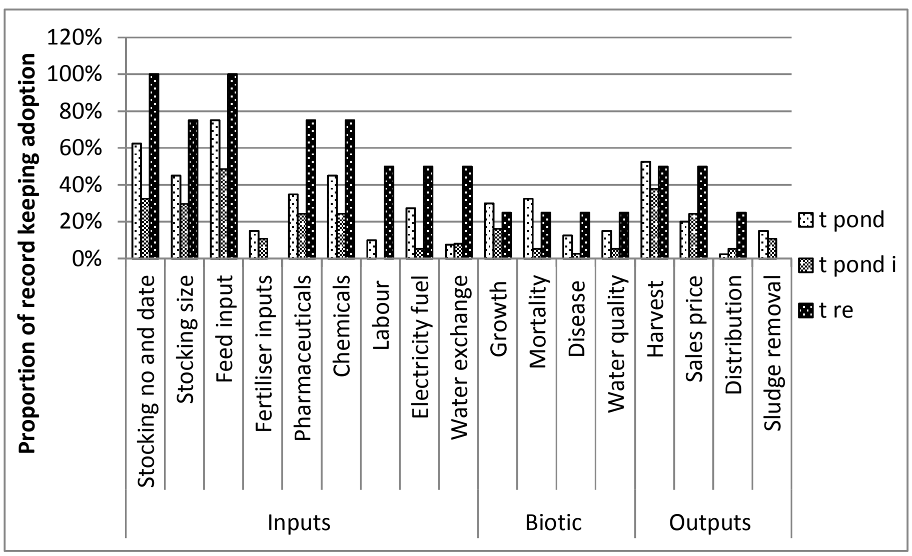

Figure 8.13 Adoption rate of detailed farm record-keeping details on tilapia farming systems, farm scale and CIQ registries of shrimp farms

(t pond= non-integrated pond tilapia farms, t pond i= pond integrated tilapia farms, and t re = reservoir tilapia farms)

Large-scale farms kept more records than small and medium farms on stocking data (number, date and size), drugs and chemicals used, labour salary, electricity and fuel, water exchange, growth sample weight, mortality and harvest (P<0.05).

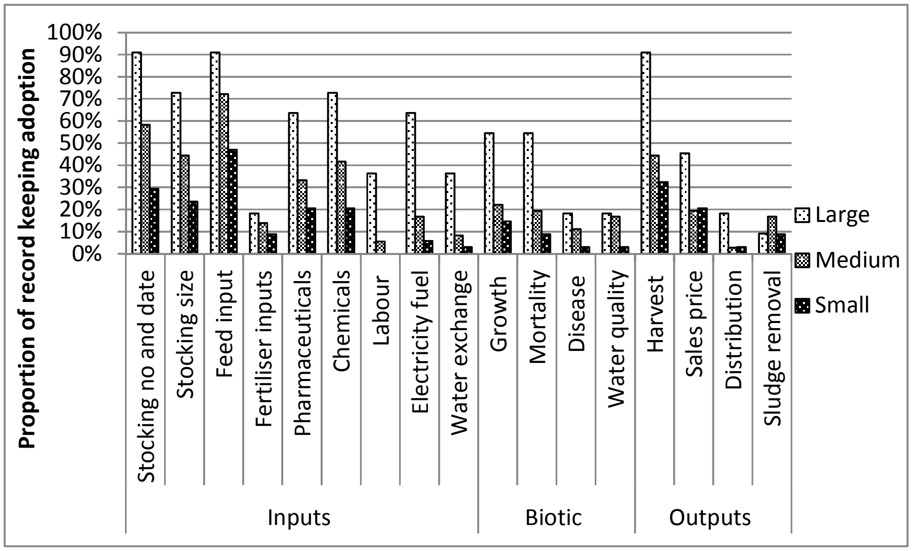

Figure 8.14 Adoption rate of detailed farm record-keeping details of tilapia farm scales

Almost no difference was found between Maoming and Hainan, except that farmers in Hainan were more likely to record mortalities than farms in Maoming (P<0.05).

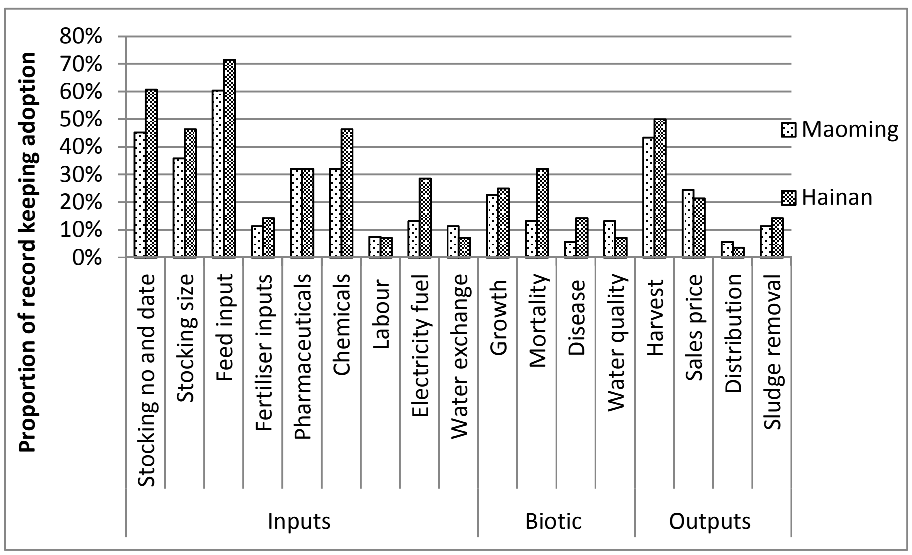

Figure 8.15 Adoption rate of detailed farm record-keeping details of tilapia farm location

CIQ farms also kept more records than non-CIQ farms on stocking no date, stocking size, feed input, chemicals, electricity and fuel, water exchange, growth sample weight, harvest and distributions

(P<0.05).

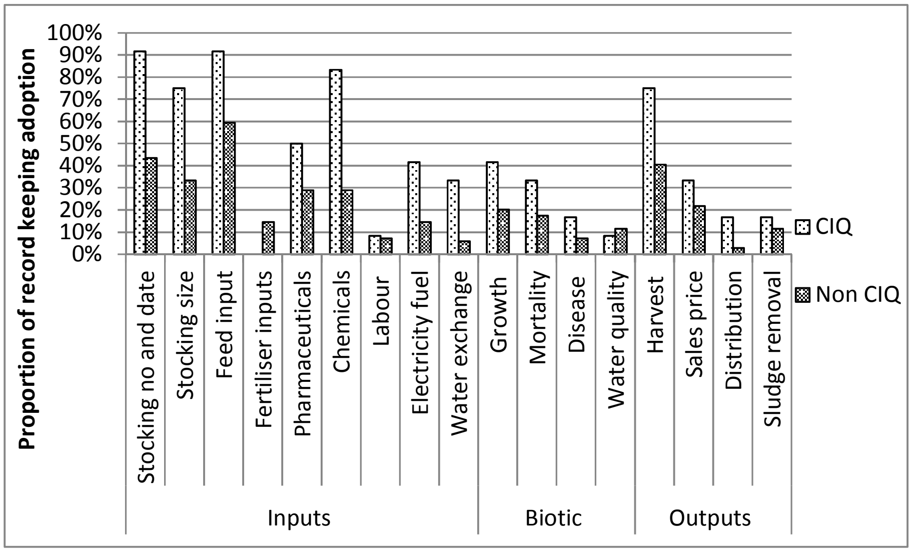

Figure 8.16 Adoption rate on detailed farm record-keeping details of CIQ and non-CIQ shrimp farms

8.3.11. Why no records

The major cited reason for not keeping records was that they had little value - they were 'not helpful' (n = 14). Other reasons included that 'they had enough experience' (n = 9), were 'too busy' (n = 6), their operations were 'small-scale' (n = 6), they simply 'didn't want' to keep records (3), had low ability (n = 2) or it was too much trouble (n = 2). Other reasons (n = 5) included high worker mobility, it not being a norm to keep records – 'nobody keeps records', that feed dealers kept records on their behalf that they 'always paid their bills on time' and that they forgot.

8.3.12. Record-keeping media

For both shrimp and tilapia farms, blank notebooks (n = 63) were the most commonly used record-keeping media, followed by custom-made printed pro-forma books (n = 12), feed company record books (n = 10), hand written pro-forma book (n = 8), government extension book (n = 5), and research organization books were also used (n = 1). No computer record-keeping system was used by farmers. Notably the research organization book was provided by the SEAT project in the early stage of AR.

The type of record-keeping media was found to be independent of farming species, farm location, farming systems, CIQ registration, but to be influenced by farm scale. More large-scale farms use their own, custom-made printed pro-forma books and government extension books, and more medium-scale farms used hand-written pro-forma books and feed company record books ($P<0.05$).

8.3.13. Record-keeping form

Most of farmers reported they kept an individual pond daily records (n = 79), and some kept farm level inventory (n = 15), only one reported keep a multiple pond daily records.

Record-keeping form was found independent of farming species, farming systems, and farm location, but it’s dependent on farm scale and CIQ registration. More large and medium-scale farms keep individual daily pond records than small-scale and more CIQ farms kept individual pond daily records ($P<0.05$).

8.3.14. Profile of record keepers

Record keepers were mainly male (n = 79), female (4) and couples (n = 3). Most of them were owners of their farm (n = 46), followed by workers (n = 22), family members (n = 11), Manager/Technician/Accountant (n = 10), and both owner and worker (n = 2). Most only had a middle-school education level (n = 43), followed by high school (n = 20), primary school (n = 10), B.A./B.S.c (n = 3), and less than primary (n = 2).

8.3.15. Farm information channel

Among 151 surveys, 37 farmers reported they had access to a computer, 43 farmers reported they had access to the Internet. Many of these used computers (n = 29), followed by mobile phones (n = 3). The most popular use of the Internet was for sourcing information (n = 11), entertainment (n = 9), online chatting (n = 2) and online shopping (n = 1). Access to computers and the Internet were independent of farming species, farming system, farm scales, CIQ registration and farm location ($P>0.05$).

8.3.16. How long records were kept

Most farmers reported that they kept all records indefinitely (n = 32), followed by don't keep them (n = 27), kept for one year (n = 11), kept until harvest (n = 10), don't know (n = 3), and three years (n = 1).

The duration that records were kept was independent of farmed species, system, and location, but dependent on farm scale and CIQ registration. Large-scale farms tended to keep records longer than small-scale; for example, 57.9% of large-scale farms kept record indefinitely, compared with only 23.5% of medium-scale farms. Only 13.4% of small-scale farms kept records throughout. CIQ farms also keep record longer than non-CIQ farms ($p<0.05$).

8.3.17. Retention of receipts

A minority of farmers retained receipts as evidence of transactions; 27 farmers reported they kept feed receipts, 20 receipts for medicine and chemicals, 14 receipts from processors, and 14 reported they kept receipts of all kinds.

Receipt keeping was related to farming species. Shrimp farmers were more likely to keep chemical and feed receipts than tilapia farm ($P<0.05$).

8.3.18. Record analysis

The most important analysis made based on records was of profit and loss (n = 120), followed by feed utilization FCR (n = 42), growth rate (n = 12) and water quality management (n = 5).

The results show that water management based on analysis of records was only carried out on shrimp farms and that high-level shrimp farms conducted more feed utilization, growth rate and water management analysis than low-level shrimp farms. Large-scale shrimp and tilapia farms tended to conduct much more analysis than medium and small-scale farms on growth and both large and medium-scale farms had more analysis of profit and loss and feed utilization analysis than small-scale farms. CIQ farms also had a higher rate of growth analysis than non-CIQ farms. Farm location had no impact on analysis of records by tilapia farmers ($P<0.05$).

Most analysis was made by the interviewee (n = 82), followed by the boss (n = 20). Other individuals such as manager or technician (n = 7), other family members (n = 5), and by company owners (n = 2) were less likely to conduct analysis of records themselves. Large-scale and CIQ farms were more likely to have the manager, technician or head of the company being responsible for analysis than medium and small and non-CIQ farms ($P<0.05$).

The most common approach to analysis is using a calculator (n = 81) followed by manually (n = 18) and computer (n = 2).

Thirty seven farmers also reported they compared performance between different farming cycles; large-scale farms were more likely to do this than medium and small-scale farms, and CIQ farms more than non-CIQ farms ($P<0.05$).

8.3.19. Record inspection

Twenty eight farmers reported their records needed to be inspected and three claimed that third parties carried out such inspections.

Record inspection and reporting were independent of farmed species, farming system, and farm location. Large farms and CIQ farms were more likely to be inspected and all three farms that reported farm records to third parties were CIQ farms ($P<0.05$). The only BAP farm (also a CIQ farm) interviewed also reported all farm records were inspected by third party certification bodies.

Local fisheries authority conducted most inspections (n = 17), followed by feed company (n = 7), the certification body (n = 2), and local CIQ (n = 1). Large-scale farms were more likely to be inspected by the local fisheries authority than medium and small-scale farms, and both the two farms inspected by certification bodies were large-scale farms. CIQ farms also had more inspections from local fisheries authority than non-CIQ farms. Feed companies in Hainan did more inspections than others.

The three farms reporting their records did so to the local CIQ branch, Tongwei feed company and Dongyang feed company respectively.

8.3.20. External support

Most farmers didn't report any help from outside, 45 reported they got some assistance from commercial companies and 14 from the government. Among commercial companies, feed companies were reported to provide more help (n = 15), followed by chemical dealer (n = 8), feed company and chemical dealer (n = 2), processors (n = 2) and research institutes (n = 2). The offer of free training courses was most common form of government support (n = 4), followed by communication meeting (n = 1) and provision of pro-forma record-keeping book (n = 1).

8.3.21. Record-keeping trends

One hundred and thirty four farmers declared they did not plan to keep more records and only 13 said that they were open to more record-keeping in the future. Records they would consider keeping in the future included feed (n = 2), water quality (n = 2), stocking number and date (n = 1), fertilizer (n = 1), management (n = 1), weather (n = 10) and one reported he will change from farm-level inventory to individual pond records. These were independent of farmed species, farming system, farm scale, farm location and CIQ registration. The reasons explaining their lack of interest in keeping more records was led by 'records were not helpful' (n = 18), and they have enough experience (n = 7), too much trouble (n = 7), no time (n = 7), don't want (n = 3), and small-scale (n = 2).

The most identified trends were the change from more records to no/fewer records (n = 13), from no/fewer records to more records (n = 4), and few other (Table 8.2). The trends were independent of farmed species, farming system, farm scale, farm location and CIQ registration. Various reasons were given by farmers for these trends (Table 8.2).

Table 8.2 Farm record-keeping trends and reasons

Record-keeping trends	Reasons
From no/fewer records to more records (n = 4)	Inspired by SEAT record-keeping book (n = 1)
	convenient for farm management (n = 1)
	learned it from training (n = 1)
	Farm scale became bigger (n = 1)
From more records to no/fewer records (n = 12)	became experienced (n = 3)
	too busy and no time (n = 3)
	too much trouble (n = 2)
	worker always changing(n = 1)
	feed company stopped asking them to keep record(n = 1)
	had partner before, no partner now so no record needed (n = 1)
	scale became smaller(n = 1)
Changing sometimes (n = 1)	adjusted, following request from head company (n = 1)
Start use pre-forma recording book (n = 1)	profit calculation easier(n = 1)

8.3.22. Key informant questions

The reasons given why many farmers don't keep full records included not helpful (n = 11), small-scale (n = 9), busy (n = 8), private operation no need to report to third parties (n = 8), trouble (n = 7), they have enough experience (n = 6), low ability (n = 2), and no such habit (n = 1).

For the question what type of farm doesn't keep records, responses given included small farm scale (n = 7), sole proprietorship farm (n = 2), farmer has sufficient experience (n = 1), farmer thinks it unnecessary (n = 1) and laziness (n = 1).

8.3.23. Respondent biography and record-keeping

8.3.23.1. Gender, age part-time/full-time status, and years of farming experience

More than 90% (94.3%; n = 142) of respondents were male and no significant difference of record-keeping adoption was found between male and female respondents (P>0.05).

No significant difference of record-keeping adoption was found between different age categories of respondents (P>0.05).

No significant difference of record-keeping adoption and detailed record was found between part-time and full-time farmers (P>0.05). However, more full-time farmers used their own printed pre-forma record-keeping book than part-time farmers (P<0.05).

A general trend was observed in which more experienced aquaculture farmers reported more record-keeping types and higher adoption rate, but was only significant among shrimp farms (P<0.05) and no significant difference was found among tilapia farms (P>0.05).

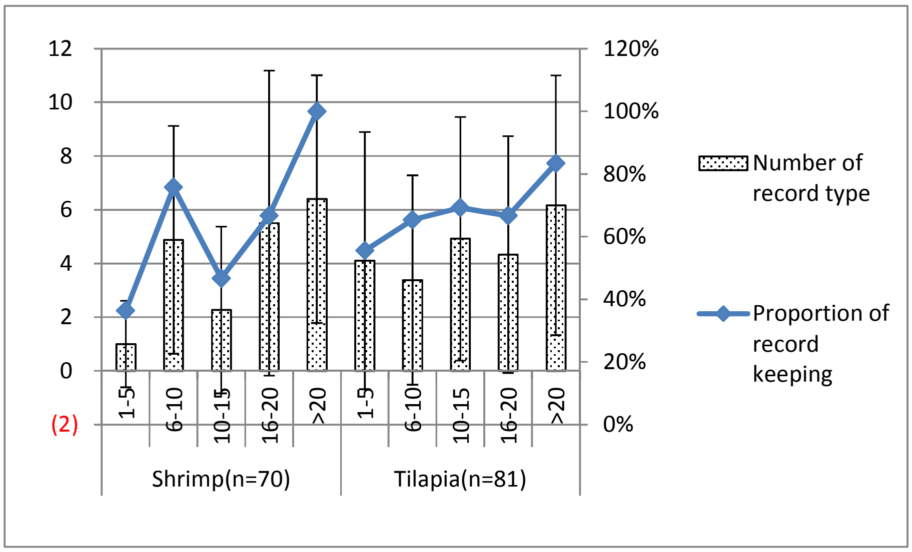

Figure 8.17 Number of the record type and record-keeping adoption rate of different years of farming experience groups

8.3.23.2. Farm role and record-keeping

A significant difference was found among respondents with different farm roles. Respondents who were manager or technician had higher proportion of record-keeping (P<0.01), and reported keeping more detailed records than respondents who were the owner (P<0.01), but no difference was observed between respondents who were workers and owners or manager and technician (P>0.05) (Figure 8.18).

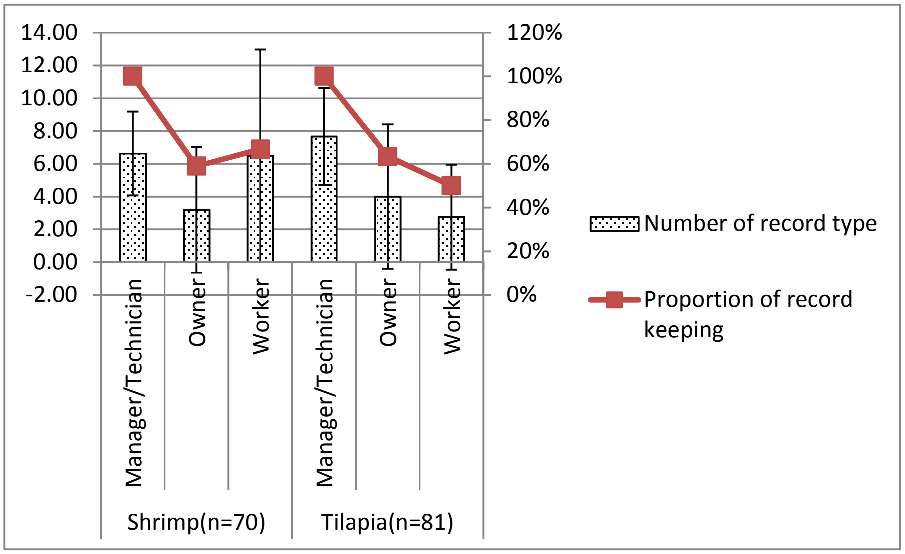

Figure 8.18 Number of the record type and record-keeping adoption rate of different farm roles

Respondents who were managers or technicians reported keeping more records for stocking numbers and date, stocking size, feed input, labour salary, disease symptoms, total harvest, and sales price than those respondents who were farm owner or worker (P<0.05), but no differences were observed for fertilizer input, pharmaceuticals, non-drug chemicals, electricity and fuel, water exchange, growth sample weight, mortality, water quality, distribution and sludge removal (P>0.05). Besides record contents, more respondents who were managers or technicians reported using their own printed pro-forma record-keeping book than respondents who were farm owners or workers (P<0.05).

8.3.23.3. Education level and record-keeping

Education level of respondents also affected record-keeping practice. Statistical tests show significant differences between different education levels (P<0.05), and respondents with higher education levels had higher proportion of record-keeping and kept higher number of detailed records than those with lower education levels (Figure 8.19).

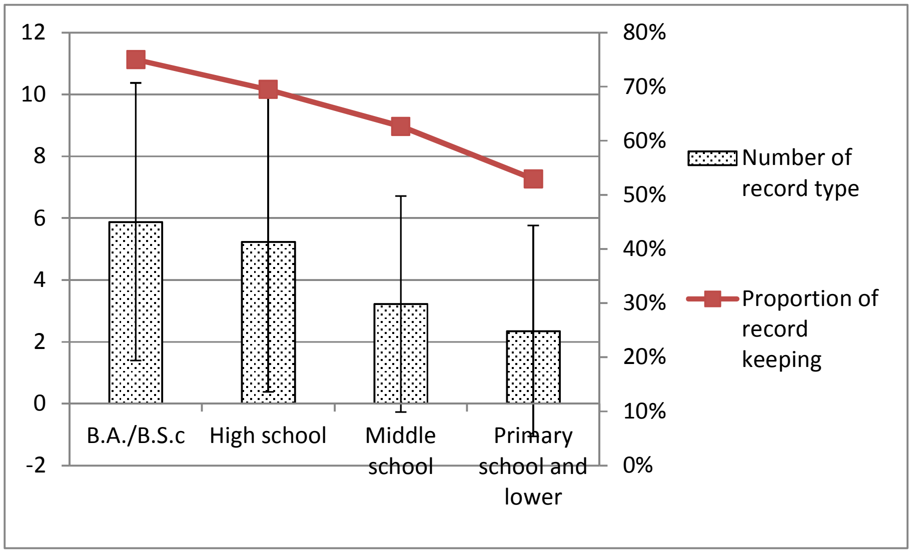

Figure 8.19 Proportion of record-keeping and number of detailed records reported by respondents with different education level.

Respondents with high education levels, such as B.A./B.S.c and high school reported keeping great number of detailed records of stocking number and date, chemicals, labour salary, electricity and fuel, water exchange, growth sample weight, water quality, total harvest, sales price and distribution than those respondents with lower education levels such as middle school and primary school (P<0.05), but no different for stocking size, feed input, fertilizer input, pharmaceuticals, mortality, disease symptoms, and sludge removal (P>0.05).

8.3.23.4. Previous occupation and record-keeping

Respondents in aquaculture/fishing and student/unemployed groups had higher proportion of record-keeping and kept more number of detailed records than other groups (P<0.05) (Figure 8.20).

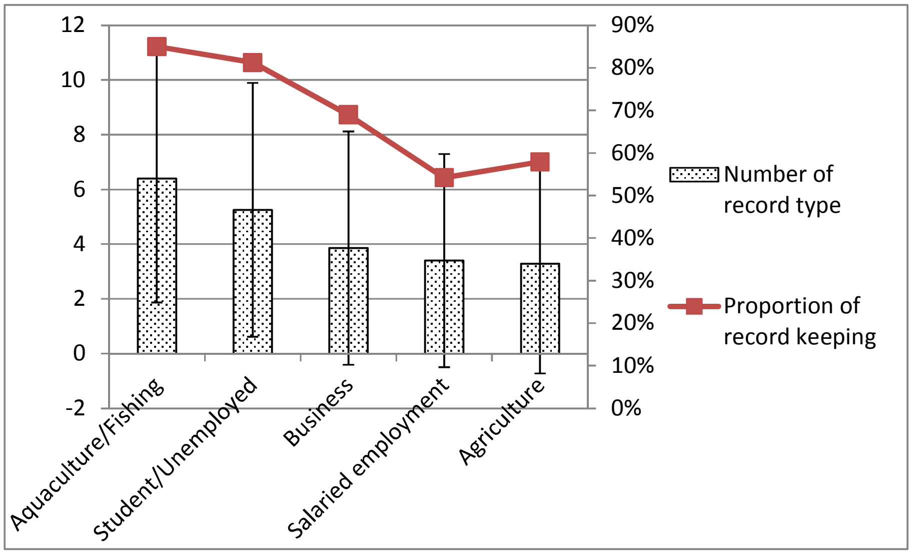

Figure 8.20 Proportion of record-keeping and number of detailed records reported by respondents with different previous occupation

Respondents in aquaculture/fishing and student/unemployed groups reported kept more records of feed input, fertilizer input, pharmaceuticals, non-drug chemicals, water exchange, growth sample weight, mortality, and water quality than those respondents in other groups ($P<0.05$), but no difference of stocking numbers and date, stocking size, labour salary, electricity and fuel, disease symptoms, total harvest, sales price, distribution, and sludge removal ($P>0.05$).

8.3.24. Feedback on interim results of record-keeping research at the workshop

Workshop participants included 45 stakeholders who came from different sectors along the value chain such as tilapia farmer, feed company staff, chemical dealer, hatchery owner, processing plant staff and government officers. Twenty one record-keeping book research feedback forms were collected during the two day workshop.

No mistake in interim results was found by participants. The benefit of record-keeping identified by participants are good for farm management (n = 13), good for building traceability system (n =

8), good for farm accounting (n = 2) and good for government inspection (n = 1).

Reasons given by participants for why many farmers don't keep records include: too much trouble (n = 11), no awareness of benefit of record-keeping (n = 8), useless (n = 8), low ability (n = 5), small-scale (n = 2), not related to product sales (n = 2), and no time (n = 1).

Participants also gave suggestions on how to improve record-keeping, including government regulations (n = 11), raising awareness (n = 7), economic incentives (n = 5), training and education (n = 5), and farmers associations (n = 1).

Participants proposed that in order to make record-keeping books easier to use, the most important thing needed are technical training (n = 8), training videos (n = 4), training document (n = 2), government technical support (n = 1) and an online Q and A system.

Participants also proposed that 1) although farm record-keeping is important, in reality it is not easy to adopted; 2) there is a need to simplify record-keeping systems, and 3) that recorded data must be analysed in a timely and scientifically sound manner.

8.4. Discussion and conclusion

8.4.1. Major factors related to record-keeping

Although farm record-keeping is a key practice of successful farming, many studies reported most farmers don't keep records, especially small-scale farmers, and very few farmers use computerised farms record-keeping tools (Akcaoz *et al.* 2009; Devonish *et al.* 2000; Muhammad *et al.* 2004; Tham-Agyekum *et al.* 2010). There are many factors related to farming practice, including drivers and motivations such as farmer's goals and attitude to risk; abilities and capabilities such as cognitive and intellectual skills; and biography, e.g., background and experience (Viloria Carrillo 2010). Record-keeping depends on factors such as the level of education and skill of the fish farmer, the interest of the farmer in good management and profit, the size and organization of the fish farm, and the external assistance available to the farmer (FAO 1998).

This study found the record-keeping was mainly affected by farm scale and CIQ registration, while species, farming systems and farm locations had lower effects on record-keeping practices. Large-scale and CIQ farms had higher adoption rates of record-keeping, more detailed records and more record analysis. Most farmers use blank notebooks as record-keeping media, although a certain number of farmers use computers and internet, no computer record-keeping system was used by farmers. Some farmer reported a requirement to get their records inspected, and a few reported the need to submit it to third parties. External support was found to increase the interest in, and application of, farm record-keeping. Farmers disinterest in record-keeping was related to a perceived lack of value of such records and/or that they 'had enough experience'.

8.4.1.1. Drives and motivations

Lack of incentives was seen as a major constraint inhibiting farmers from record-keeping (Tham-Agyekum *et al.* 2010). This study found similar results as most farmers who don't keep records claimed they were useless and time consuming. The cost and benefits of traceability system are critical for its success (Karlsen 2011), and a similar situation applies to farm record-keeping. Record-keeping is very time consuming and was seen as a burden by farmers (Gerloff 2012; Taylor 2001; Tham-Agyekum *et al.* 2010), through increased production cost (Xu *et al.* 2012). It was found in organic certification systems that most farmers don't want the costs of documentation such as record-keeping (Albersmeier *et al.* 2009). An earlier study estimated a record-keeping cost of USD 1,500 farm^{-1} year^{-1} (20 minutes a day for 240 days year^{-1} at USD 20 hour^{-1}) (Estrin 2010). However, "no benefit and no time to keep records" was identified as the most important constraints to promote farm record-keeping in many studies (Chembezi 2002; Devonish *et al.* 2000; Tham-Agyekum *et al.* 2010). If there is no benefit of keeping records, given the additional costs of doing so, farmers are unlikely to change their views.

Ragoonath-Devonish (2005) found sales and expenditure were the most kept record. This study found similar results, as feed input was the most frequently recorded type kept by both shrimp and tilapia farmers, followed by pharmaceuticals by shrimp farmers and stocking numbers and date by tilapia farmers. Total harvest was another important record type for tilapia farmers. The record keeping type also reflected that farmers' motivations for record keeping were mainly economic interests.

8.4.1.2. Abilities and capabilities

The present study found that most farmers had low education levels (more primary and medium level education than high-level education), and no or little computer knowledge, all causing practical constraints to record-keeping and analysing records. This was confirmed by other studies. Tham-Agyekum *et al.*, (2010) concluded that the farmers' inability was an essential constraint to keeping useful records. Low literacy and numeracy rates of farmers, complex farming systems, and a lack of awareness and incentives are the major reason for the low adoption of record-keeping (Bachmann 1998; Chagunda *et al.* 2006; Minae *et al.* 2003). Engler & Toledo (2010) found younger and more educated farmers are more likely to keep records.

8.4.1.3. Biography

Although others have reported farm record-keeping was independent of age, gender, farm size, previous education and years of farming experience (Devonish *et al.* 2000; Mariene & Agriculture 1995; Tham-Agyekum *et al.* 2010), we found record-keeping was dependent on farm size, previous education, years of farming experience, and pervious occupation, but independent of farmers' age and gender. Viloria Carrillo (2010) found similar results as farm record-keeping was negatively affected by famers' experience. This study also found farmers' experience was one of the major factors affecting farm record-keeping. Although chi-square result in this study showed more experienced farmer reported more record-keeping, the trend analysis suggests that farmers under similar circumstances are unlikely to increase record-keeping. Devonish *et al.* (2000) found that full-time farmers tended to keep farm records more than part-time farmers but no difference was found between them in this study.

8.4.1.4. Social environment

Social economic factors do appear to provide important incentives for record-keeping, such as a personal credit system, microfinance system, and personal income tax systems (Anrooy 2004; Carkner 2001; Chembezi 2002; Devonish *et al.* 2000; Tham-Agyekum *et al.* 2010). However, these external drivers do not exist or function well in China, especially among small-scale farmers. Chinese legislations doesn't have a clear and universal requirement for farm records. In order to manage animal immunization in the livestock industry, Ministry of Agriculture of China (MOA) promulgated the 'Control Measures for Animal Immunization Marking' in 2002, and then updated it to 'Control Measures for Animal Marking and Livestock Breeding Files' in 2006 which required livestock and poultry identification and record-keeping at the farm level (MOA 2006c). For aquaculture, the "Administrative Regulation of Quality Safety for Aquaculture", which has been in force since 2003 also required record-keeping (MOA 2003) but this study shows that the regulation has either not been implemented or enforced. For exported farmed seafood, the "Export Aquatic Traceability Procedures (For Trial)" introduced in 2004 required all aquaculture farms wanting registration for export to keep farming records for production, chemical and feed use (China Entry-Exit Inspection and Quarantine Bureau 2004). All exporting companies are required to register at their provincial CIQ for a sanitation registration, and keep detailed production records of their sources of raw material (Gale & Buzby 2009). This study confirmed that most CIQ farms do keep farm records, and some CIQ farms need to submit their farm record for inspections. CIQ farms also keep records longer than non-CIQ farms because CIQ has requirement for them to keep records two years after farming cycle finished (China Entry-Exit Inspection and Quarantine Bureau 2004). However, CIQ farms only account for a very small proportion of aquaculture farms. Most of the farms are small or medium-scale and do not have CIQ registration. Moreover, since the Chinese central government cancelled the agriculture tax in 2005, farmers no longer have a tax obligation (Zhou 2007). Although the effect of cancellation of agriculture tax is still being debated, it's clear that in terms of incentives for farmers to keep records, it has been a retrograde step. Record-keeping practice has been found to be positively related to access to credit (Chembezi 2002; Devonish *et al.* 2000; Tham-Agyekum *et al.* 2010). However, no such linkage was found in this study. In China, the agriculture related small loan company only recently started (2005, Chen 2012) and as formal loans taken by a farmers from a bank remains uncommon, farmers tend to buy their feed from feed dealers partly or fully on credit and pay back after harvest. Such informal credit doesn't require farm records.

Modern aquaculture insurance also requires farm record-keeping (Anrooy 2004). However, the aquaculture insurance has not been widely adopted in China, mainly due to the shortage of risk assessment skills and a reluctance of insurers (Godfrey 2012).

Aquaculture certification in China's aquaculture sector are still at a preliminary stage (NBSO 2010b). Although both domestic certifications, such as green food and harmless food, and international certifications such as HACCP, ISO and ASC exist in China (NBSO 2010b), only very few farms were certified in the small-scale farm dominated aquaculture sector in China. This study found very little linkage between farm record-keeping practice and certification.

Low awareness of the importance of farm record-keeping on farm economic performance is a constraint (Minae *et al.* 2003). In such social and economic environments there is no requirement for farm record-keeping from outside to remind farmers, and it's not surprising that farmers are not so aware of the importance of farm record-keeping.

8.4.2. Debate on the full traceability

Traceability exceeds all existing food security concepts (Auernhammer 2002) due to its multi-disciplinary nature (Chiavaro *et al.* 2011). A fully traceable supply chain is believed to be achieved by including both chain traceability and internal traceability (Porto *et al.* 2011; Storøy *et al.* 2013; Thakur & Hurburgh 2009). In the current traceability systems, include both chain traceability and internal traceability, are mainly information systems based record-keeping (Golan *et al.* 2004a; Smith et al. 2005). Normally an internal traceability system has much more information than the external system (Karlsen 2011; Moe 1998). Even though many food producers have good electronic internal traceability system, information exchange between different producers is still time consuming or difficult due to the diversity and proprietary nature of the respective internal systems (Storøy *et al.* 2013). Economic feasibility is also important for a traceability system (ISO 2007). However, no food traceability system is complete because food is a complex product and tracking every input and process would be enormous and costly (Golan *et al.* 2004a).

Traceability was perceived as a double-edged sword as it can obtain premiums for farmers, but bring more responsibility to them (Smith *et al.* 2005). The different level of requirements for traceability in different countries also produces inequality and disputes in the international market (Souza-Monteiro & Caswell 2004). Record-keeping and traceability system on its own cannot guarantee food safety (ISO 2007) or create credence attributes by themselves. They provide evidence and need an effective safety control system based on those evidences (Golan *et al.* 2004a). Implementation of a traceability system for seafood is much more difficult than terrestrial animals and products, the commonly used packaging and labelling being no guarantee of the contents (Håstein *et al.* 2001). In the practice of aquaculture, for example, both samples of feed and feeding records are needed to make accurate assessments of feed quality. Food safety can be affected by many factors: environmental pollution, for example, is not easy to detect or record on farm.

On the consumer side, the high numbers makes recall difficult and sometimes impractical. In US, the supermarket chain club card or credit card information has been used to track sales and enhances the potential for targeted recall information (Golan et al. 2004b). However, such activities could produce an ethical conflict with consumer information and privacy protection. For example, Popper (2007) argued that consumers, the presumed beneficiaries of traceability systems, will probably resist direct incorporation (and full benefit), favouring their privacy over their safety. Thus the development of public-sector traceability systems demands more careful consideration.

Based on the current status of low farm record-keeping adoption and the scattered small-scale farms that dominate aquaculture industry in China, and all the social-economic background, it does not seem feasible to promote full traceability systems at present. The full traceability of farmed seafood could be one of the ultimate goals for the future, and the steps to achieve it should be clearly designed, which could start from external traceability only. Current CIQ systems which just provide an external traceability system to export farmed seafood value chain, may have resulted in inequity between export and domestic consumers, but have been a necessary starting point to explore and build full traceability system in the farmed seafood value chain in China.

8.4.3. Precision aquaculture

Record-keeping practice and internal traceability system can bring many advantages, such as possibility of improved process control, cause-and-effect indications, better planning, better grounds for implementing IT solutions to control and management systems (Moe 1998). Farm information systems allow farmers to control and maintain production quality by handling standardised multi-source data to achieve internal traceability (Moe 1998; Porto *et al.* 2011). Computerized record-keeping systems are more accurate and achieve real time access to current information relating to a specific stock (Dillon & Derrick 2004), and can provide information for decisions, enhancing convenience of use and increasing efficiency (Wolf *et al.* 2011). Computer systems can also be a much more powerful tool for analysis than handwritten systems, as once information has been inputted reports and analyses can be created, changed and printed, monthly or annual summaries can be produced to identify strengths and weaknesses of an operation (Gerloff 2002; Steinberger *et al.* 2006). One study showed farmers who used computers for financial or production record-keeping or who gathered information from the Internet had higher farm annual gross sales (Batte 2005). In the US, on-farm computers were used by 44% of all farmers and the most frequent task was financial accounting; 80% farmer who owned a computer also use the Internet for communication, transactions processing and information retrieval (Batte 2005). Farm computer adoption was found to be related with farmers' age, education level, and number of applications in the computer (Batte 1990). Younger farmer or farmers who worked year-around away from the farm were more likely to use a computer for the farm business (Batte 2005).

Since the inspiring concept of '*Precision agriculture*' (Auernhammer 2002), new information technologies related to record-keeping and traceability were developed, such as accurate (precision) and informed crop management, operational and recording systems, transport information management and decision support systems (Ruiz-Garcia *et al.* 2010). Precision farming techniques are currently being developed which employ GPS technology to monitor and control the position of machinery and enable measured delivery of seed, fertilizer and pesticides in addition to the detection of soil and plant quality which enables the early detection of diseases (Mampan *et al.* 2011). Precision farming can enhance income and yield per drop of water and per units of land and time, reduce the cost of production and improve productivity on an ecologically sustainable basis (Swaminathan 2006). More importantly, manual manipulation of farm records can be avoided by using precision farming technology and an automated computerised farm management system (Auernhammer 2002).

Precision agriculture can be achieved based on decision support systems and accumulated agriculture products and farming data (Kondo 2010). Computer based decision systems include databases, geographical information systems, models, knowledge-base or expert systems, and 'hybrid' decision support systems (Ellis *et al.* 2004), and can create valuable new information and has the potential to increase farm profits (Nuthall 2004). Compared to traditional record-keeping systems, novelty PDA-based record-keeping and decision systems with fertilization recommendation model and early warning model of pesticide usage have added more functions to ongoing decision making for farming practice (Li *et al.* 2010). The revolution in information technology should make it feasible for farmers in Asia to access needed information and adopt precision farming techniques (Swaminathan 2006).

For aquaculture, advanced computerized record-keeping, farm management and decision support systems were developed wildly used in EU for salmon farming, such as GMT central feeding system[13] is fully automated system with full reports from feeding system and all connected sensors, and Fishtalk[14], a comprehensive, scalable software solution for aquaculture production control, planning, costing, and budgeting in one complete package with extensive reporting capabilities. Such computerized feeding systems that can adjust feed quantities depending on temperature, season and time of day, using sonic or video monitors can judge stock movement and behaviour, or monitor levels of uneaten food, and thereby control feeding rates even more accurately (Muir 2005).

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[13] http://www.steinsvik.no/en/steinsvikaqua/feeding-systems/central-feeding-system/

[14] http://fishtalk.no/

In this study, very few farmers reported using computers and the internet, and only one large-scale vertically integrated farm reported they use computers to manage farm records. Compared with the widely adopted computerised farming management systems in developed countries, shrimp and tilapia farming in China is more like a traditional peasant economy. Computerised farm management systems are a key support for the high productivity of western aquaculture, which could also be a direction to develop modern aquaculture in China.

8.4.4. Possible improvements

There are two dilemmas that need to be resolved. One dilemma is easy-to-use farm record-keeping system more suitable for less formally educated farmers, but record analysing requires sophisticated management tools such as a computer system. On the one hand, farmers don't like paperwork such as record-keeping and normally no office or desk is available for farmers to keep records, so farm record-keeping should be simple and all records should be kept in one book (Devonish et al. 2000; Gietema 2006; Mariene & Agriculture 1995; Pomeroy 2003; Tay et al. 1992; Yami 2009). The current study also found a similar requirement from farmers and simple record-keeping systems were also suggested by stakeholders in the workshop. It was also believed that different farm scales should adopt different record-keeping systems; for example, larger and more commercial farm with more technically qualified staff can adopt more detailed record-keeping system (FAO 1998). On the other hand, farm records need to be analysed in order to fully utilize information behind farm record data, requiring good computer software to do a good job. To fulfil the food safety requirement, HACCP system was believed as necessary for aquaculture farms and it's actually based on sophisticated record-keeping system (Gall & Rivara 2000; Reilly & Käferstein 1997). The gap between sophisticated record-keeping requirement by

HACCP system and data analysis, and the reality of low adoption and simple record-keeping practice by farmers seems huge and needs to be narrowed.

Another dilemma is between the top-down and bottom-up approach to promote farm record-keeping. From a top down perspective, small-scale and scattered farms make it impractical to monitor and supervise them by the government or any third parties due to the high regulatory cost and low possibility of prosecution. From bottom up perspective, there is insufficient incentive or motivation for them to make major innovations such as adopt farm record-keeping.

To make sure all farmers keep records, one option is apply pressure through legislation. However, Taylor (2001) argued legislation cannot sufficiently motivate or pressurise small companies due to the low risk of prosecution (within the regulatory system of most countries). Scattered small and medium-scale farms are not easy to supervise by government and law enforcement departments; there is high possibility of widespread law breaking after such legislation is implemented. This was observed in this study as many farmers don't keep any farm record, in direct contravention of the "Administrative Regulation of Quality Safety for Aquaculture". The farm-level registration and linked traceability scheme in Guangdong province is unlikely to succeed.

The second common way is through extension, demonstration, and awareness raising activities. It was believed building farmers' capacity through training courses was more effective in raising production and income than direct financial support (Murshed-E-Jahan & Pemsl 2011). Rangarajan & Pritts (2002) reported additional record-keeping training for small-scale farmers is specifically required. However, the reality shows after nearly a century effort, extension service still working on helping farmers with farm record-keeping system (Doye 2004). The lack of incentives to farmers is probably the key issue rather than more extension and education even if it is effective at enhancing farmers' awareness and ability.

There are also approaches that provide incentives or motivation, such as enhanced efficiency through record-keeping and data analysis or through paying a premium for certified food. However, many farmers reported no benefit from record-keeping, which is possibly caused by two reasons. One is that hand-written records used by most farmers make record analysis very difficult, and the survey shows no difference in technical and economic efficiency between record keepers and non-record keepers (Ragoonath-Devonish 2005). Another is that even if efficiency is improved by record-keeping and analysis, the small size of such farms makes access to improved economic returns still a challenge (Tham-Agyekum *et al.* 2010). Gietema (2006) also reported even if technical solutions are available for small-scale farms, the capital costs of implementing them may be too costly, even if credit is available.

Practical extension is very difficult for scattered and small-scale farmers, as indicated by the low delivery rate of SEAT record-keeping book via the post system; remote farm sites and complicated administration systems makes information delivery very difficult and more sophisticated activities are likely to be a major challenge.

The high number of small-scale, scattered farms makes it difficult and very expensive to deploy record-keeping systems in all farms. Promotion of record-keeping proved unsuccessful in small-scale farms due to their simple practices (Chagunda *et al.* 2006), scarce resources and scattered households (Li *et al.* 2010; Ruiz-Garcia *et al.* 2010; Wang & Li 2006). Larger farmers are more likely to keep records for management purposes (Chagunda *et al.* 2006; Devonish *et al.* 2000;

Viloria Carrillo 2010). It was also reported that due to the small-scale and scattered fresh cucumber production in China, record-keeping and information communication is very difficult (Li *et al.* 2010). It is believed that the scattered location and poor socioeconomic conditions of small-scale farms have been a major constrains in implementing improved farming practices (Srinath *et al.* 2000). It is highly likely that because aquaculture is dominated by small-scale and scattered farms has been the root cause of such problems as the low adoption rate of farm record-keeping, and difficulties in enhance food safety, or building traceability system.

8.4.5. Value chain integrated solution

One possible strategy to resolve the food safety problem is from the value chain aspect, such as better control of producing and trading of pharmaceutical and chemical and keeping dangerous chemicals out of supply chain altogether (Huang *et al.* 2012). The aquaculture value chain includes major suppliers such as hatcheries, feed companies and chemical companies. Unlike small-scale and scattered farms, these companies are much more capable, with better knowledge and financial situation, and much easier to be supervised by the government and law enforcing department. Farmers, especially small-scale farmers, lacked sufficient knowledge of disease diagnosis to use pharmaceuticals properly, but they are highly influenced by chemical dealers' promotion and tend to use chemical excessively and inappropriately (Rico *et al.* 2012). Success stories can be found, however, such as the control system for the use of medicines in Norwegian aquaculture, which not only require farming records, but also require all aquaculture medicines to be prescribed by a veterinarian and the veterinarian must send a copy of the prescription to the authorities, and sale of aquaculture medicines from medicine industry are also need report to the authorities (Maroni 2000). After implementing such a system, the abuse of chemicals and food safety risks are perfectly controlled. A similar system could also use for seed and feed control. Feed companies, for example, could be required to keep feed samples of every batch product (rather than farmers) for traceability purpose.

Since record keeping is a key step in building HACCP system and obtaining many food-safety and broader sustainability certifications such as Eurep-GAP (Trienekens & Zuurbier 2008), this research may be most useful to feed into another round of AR with certifiers/regulators and/or other private sector value chain actors who have a vested interest in greater traceability. This might include feed and drug producers/distributors who would benefit from best practice use of their products-could they support appropriate computer based record-keeping that would feedback results to farmers improving farm performance. Instead insist farm level research, following AR of this study could move to value chain level (Figure 8.21).

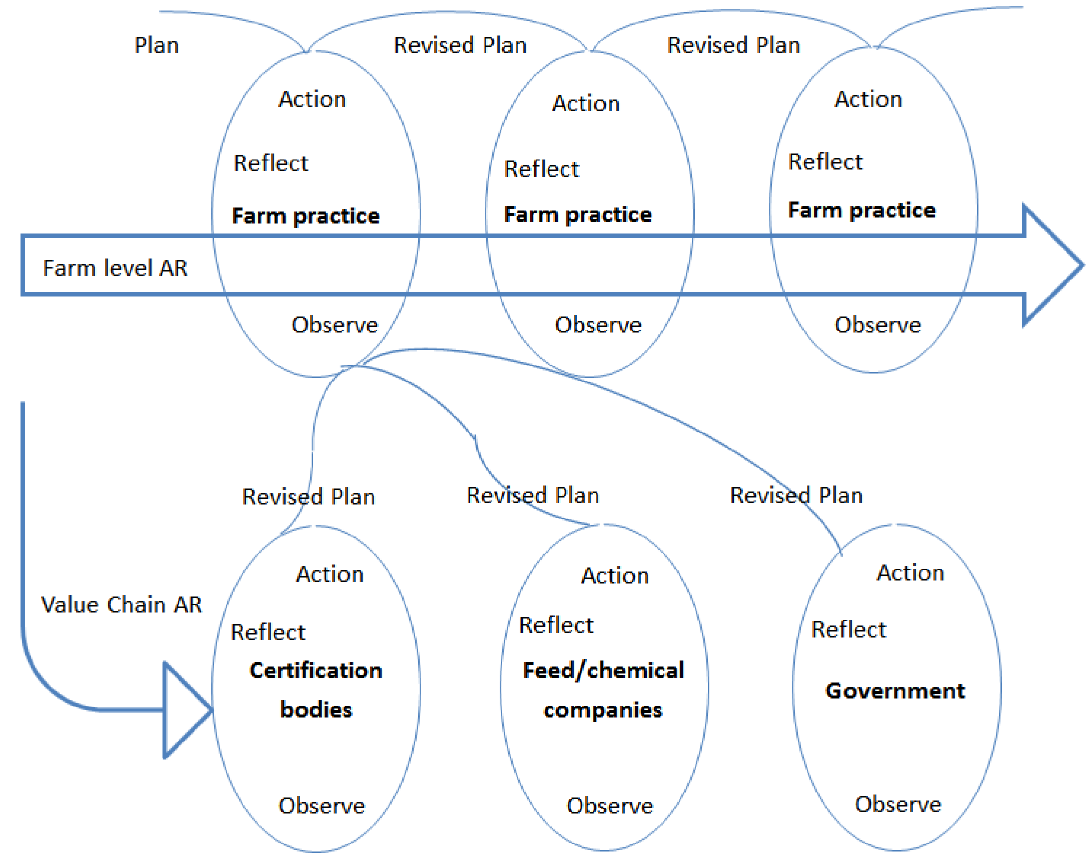


Figure 8.21 Action research cycles (adapted from Hopkins 2002) and different level of AR

8.4.6. Further social-economic reform

Low incentive and low ability of farmers to keep records, especially of small-scale farmers are the biggest constraints. Promoting farm record-keeping is unlikely to be successful in current social-economic context. Although good examples such as precise agriculture and automated farm management system in salmon farming in developed countries point a sound way, they are unlikely to be implemented in China in the near future. Along with rapid economic growth and higher industry development level in China, agriculture became a weak and vulnerable industry. Further social-economic reform needs to be done to change the scattered, small-scale farm dominated agriculture and aquaculture. Possible methods include reform in land right and market, and promotion of farmers' organisations, such as farmer cooperatives. Future farm consolidation or collaboration to larger scale operations and a reduced number of farms might support the move towards more comprehensive farm record-keeping, in time leading to more advanced precise agriculture and automated farm management systems.

9. CHAPTER 9: Discussion and conclusions

9.1. Sustainable intensification, diversification, and extensification

The general trends of the aquaculture industry in China were identified in chapter 3, which included intensification, diversification, and extensification. For tilapia, shrimp, macrobrachium prawns and striped catfish farming, the trends of intensification and diversification were elaborated in chapter 4 and chapter 5. The success of tilapia and whiteleg shrimp farming was linked to their biological characteristics suitable for intensified farming, and macrobrachium prawns were linked to diversified market demands.

The introduction of semi-intensive and intensive farming practice, where producers actively influence the growing condition of the fish, has been the main engine for growth in aquaculture production (Asche *et al.* 2008). As farming practice becomes more intensified, more intensive management is required, which needs greater skills, expertise, technological inputs and labour, marking a shift from quasi-peasant to quasi-capitalist and, finally, capitalist relations of production (Belton *et al.* 2012). Both intensive, single-species aquaculture and more traditional, lower-intensity aquaculture are evolving, and both will be necessary to meet the future needs for seafood (Asche *et al.* 2008; Diana *et al.* 2013).

During this process, the critical question centres on the `*type of intensification*' (Wegner & Zwart 2011). The concept of `*sustainable intensification*' was developed for agriculture firstly, which integrates biological and ecological processes into food production, minimises the use of those non-renewable inputs that cause harm to the environment or to the health of farmers and consumers, makes productive use of the knowledge and skills of farmers, so substituting human capital for costly external inputs, and makes productive use of people's collective capacities to work together to solve common agricultural and natural resource problems (Pretty 2008). Aquaculture intensification is limited by its environmental impacts (Tett 2008). Efficient aquaculture systems requiring fewer inputs and producing wider benefits and fewer wastes could be expected to be more sustainable (Muir 2005). Expansion and intensification of aquaculture are needed to satisfy peoples' demand for seafood. However, the natural resource conservation, environmental protection, and economic and social sustainability also need to be satisfied (Crab *et al.* 2012). Thus, the sustainable intensification of aquaculture industry based on such holistic objectives is advocated.

Diversification normally means a change in culture systems to include more, higher value species, and a corresponding increase in the level of inputs, or using species combinations that mitigate risk in the context of polyculture. The implications include use of higher fishmeal level in the feed, sometimes even trash fish when no formulated feed available or feed technology is developed for a novel culture candidate. However, among high value species, some may have a better ecological efficiency than others, such as the transition from *P. monodon* (piscivorous) to *L. vannamei* (omnivorous) can reduce fishmeal and fish oil input and corresponding environmental impact (Naylor *et al.*, 2009). Sustainable diversification can be a key component of with sustainable intensification, ensuring the high value species used have high ecological efficiency.

The emerging trend of extensification may also contribute to sustainability of the sector since although yields may remain low or even be reduced, overall value may increase. For example, although organic fish farming has a much lower yield than conventional practice, this may be compensated for through higher sales prices (Jia *et al.* 2013; Xie *et al.* 2013).

This study also found among different farming systems or different farm scales of shrimp and tilapia farming, there were reverse advantages between productivity in value output term and in production terms. The so called "*Hidden agriculture revolution*" in China, as the increase in output value outpaces increases in production (Huang *et al.* 2012) is also happening in aquaculture. Although productivity in value output terms has been largely ignored by aquaculture community, it is equally important to the sustainable development of the sector (Figure 9.1). Future sustainable intensification should not just intensify by higher input and higher yield, but also by higher value output, which possibly in extensification form.

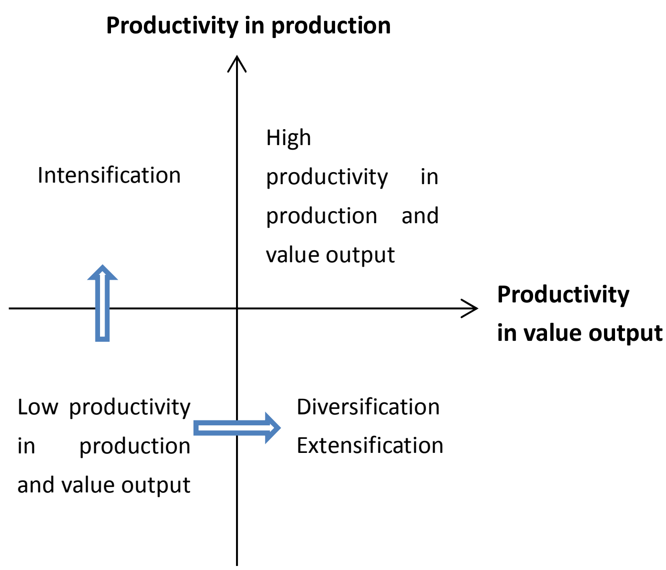


Figure 9.1 Different development strategies of aquaculture industry from low productivity to high productivity

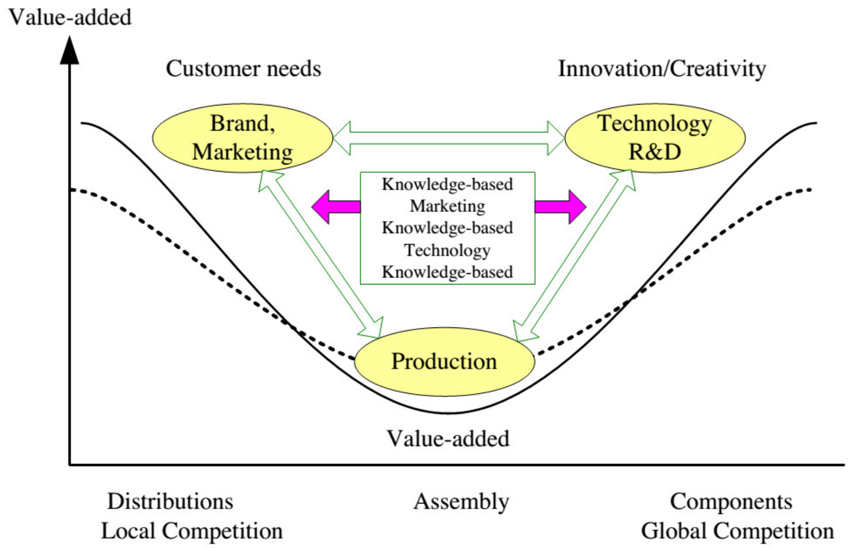
9.2. Globalization, export and domestic value chains

Although China is the World's biggest seafood exporter and importer, such external seafood trade only accounts for a small proportion of total fisheries production, most of which is consumed domestically (FAO 2012c; MOA 2012). However, the export of seafood was considered as an important foreign exchange earner for China (Li & Huang 2005), providing very significant numbers of employment opportunities (Liu & Li 2010), and to be very important for some farmed seafood such as tilapia and shrimp (Yu, 2012). For example, the whole tilapia value chain is estimated to provide more than one million jobs due to the multiple sectors in its value chain and tilapia processing still being mainly based on labour-intensive manual operation (Yang 2010). Meanwhile, through meeting the challenges of foreign markets, there is potential to enhance and upgrade the whole industry (Luo *et al.* 2007). Harmonisation of local and export value chains, however, is unlikely to occur in the short-term because of important differences between them.

Despite its leading position in the world, China's aquaculture is vulnerable to a variety of forces in a global context. Growth in production and exports is increasingly dependent on supplies of imported feed raw materials such as fishmeal and soybean and is therefore vulnerable to changes in supply and price. In China, for example, domestic soybean farming has declined rapidly because it cannot compete with imported soybeans (Chen *et al.* 2012). For both shrimp and tilapia, international competition from other countries continues to grow, reducing capacity to maintain margins. There is already a precedent, channel catfish, which lost its international market due to competition and trade conflicts over the last few years (Cui & Xiao 2012; Yan *et al.* 2013). The advantages gained by upgrading products through investment in processing capacity may be short-lived as countries with lower labour and other costs compete in these sectors. The weak pricing power in export value chains is exacerbated by a lack of ownership of brand and control of distribution channel in foreign markets, resulting in seafood exports being mainly exported cheap labour (Zeng 2011b). The predominance of hand processing in China results in higher fillet yields and less by-product than more mechanised processing methods, which is another advantage of

China’s fisheries processing sector (Clarke 2009). Although secondary processing in the EU is still popular it is believed that more value addition will move to the original producing country (CBI 2013c). One senior administrator working in a processor enterprise said, “If foreign buyers want to buy seafood from China, they must pay a reasonable price, and as a developing country, China needs technical help instead of barriers and bans from any developed country who wishes to import farmed seafood from China and require those seafood fulfil their standards” (Hill 2011).

According to the “smiling curve” theory originally developed by Mr. Zhengrong Shi, the founder of ACER Company, the value chain can be divided into several parts as brand, R&D, production, storage & transport, wholesale and retail (Figure 9.3). The profit is, however, not distributed equally along the value chain. Depending upon the product, the lowest profit is usually to be made in production, while brand and retail are related to the largest value additions. Application of the “smiling curve” theory to exported seafood does need further study. Brand development will require attention to ensuring the intrinsic values of the product are strong and consistent, that they include the fundamental consumption qualities of the product (nutritious, delicious and safe) but also credence qualities of emerging importance to both international and domestic consumers. Improving margins for in-country value chain actors will involve improving productivity, possibly reducing distribution channels with subsequent loss of some actors’ roles. Domestic aquaculture produce will come into increasing competition with imported products that are likely to be comparatively expensive but heavily branded.



Solid line is baseline scenario
Dash line is scenario of it showed enhancing the marketing and R&D will create value-added to the products or brands

Figure 9.2 The smiling curve

(Source: Wang & Tzeng, 2012)

Meanwhile, export trade was seen as a major cause of China's increasing pollution as export consumes natural resources and leaves pollutants behind causing environmental damage (Liu & Diamond 2005). The free trade system under the WTO eliminated tariffs and quotas and prohibited nontariff trade barriers and thus spread of prosperity, but the trade was seen as heavily biased toward industrialized nations of the west and means the markets of poor nations of the world are open for capture by the rich. An outcome has been that while the farmers' share of the food dollar in international market has declined, on average, across all farm products, farm gate prices now make up less than 20% of the retail price (Busch & Bain 2004). Trade remains a potentially volatile area of tension between developed and developing countries, and between the rich and the poor (Dey & Ahmed 2005). Antidumping measures are being increasingly used by nations as a means of protecting their own produce against competition from imports (De Silva & Phuong 2011). The trade liberalization brings benefit at the national level, but will generate imbalance growth at the local level, just as the shrimp farming industry widened the gap between rich and poor at the local level (Pradhan & Flaherty 2008). The complexities of food safety and public health concerns in importing countries can dramatically affect access to markets by poor citizens in developing countries (Dey & Ahmed 2005). Export-led seafood value chains need be further studied and the results could serve to inform the transparency of the value chain.

9.3. Way out for small-scale farmers

China's agriculture is dominated by 200 million small-scale farms and the successful and rapid production increases have been achieved by these farms (Gale & Buzby 2009; Huang *et al.* 2012). Farm landholdings are in decline linked to the rising number of rural households and subdivision of farms among children (Edwards 2010; Huang *et al.* 2012), the average farm size owned by a household decreased from 0.56 ha in 1980 to 0.46 ha in 2010 (China Agriculture Yearbook Editorial Board 2011).

Due to small-scale farms dominating agriculture production, current agriculture development remains mainly focused on small-scale farms (Collier & Dercon 2009). Many aquaculture development studies have emphasised not to push small-scale producers out of business or to the margins (Brummett *et al.* 2011; Bondad-Reantaso *et al.* 2012; Ito 2004; Rivera-Ferre 2009).

However, small-scale farms may not be engines for economic growth and poverty reduction and much of the focus on small-scale farms may actually hinder large-scale poverty reduction (Collier & Dercon 2009). This study found the status of aquaculture being dominated by small-scale and scattered farms was one of major reasons for low labour productivity in chapter 5, and low adoption of farm record keeping in chapter 8. Although the land productivity in production terms of small-scale farms may be higher than of large-scale farms, the land productivity in value output term was similar and they are much lower in labour productivity.

Future aquaculture development needs to consider bother land productivity and labour productivity, and a development strategy needs to consider different social economic background (Figure 9.3). While China's population growth rate has been strong increasing labour productivity might not have been a priority, but with a rapidly declining growth rate and aging demography with comparatively fewer younger people entering the labour pool, then labour productivity is becoming very important.

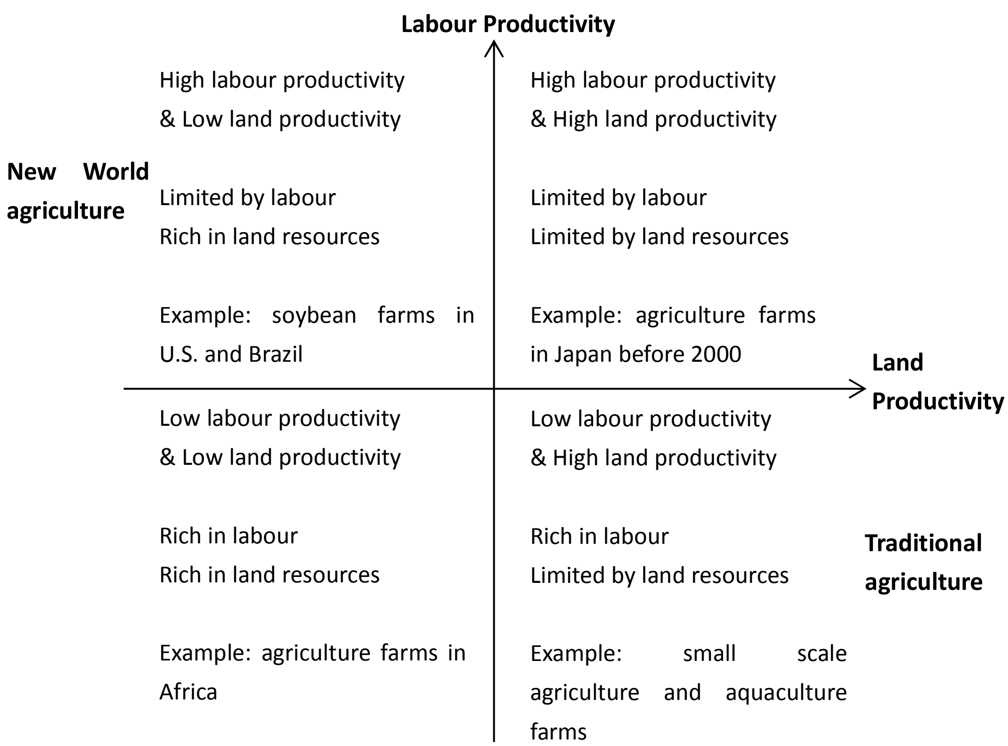


Figure 9.3 Different labour and land productivity and corresponding labour and land characters and examples

As illustrated in chapter 8, there are dilemmas in promoting better farming practices such as record keeping or building traceability systems among small-scale farms. Neither top-down regulation nor bottom-up farm level technique extension approach seems workable. The simple practices used on small-scale farms also conflicts with farm record keeping and analysis and adoption of more sophisticated systems such as HACCP.

A much more open-minded approach to different modes of production should be considered than just focusing on small-scale farms (Collier & Dercon 2009). It was argued that "*...there is a need for a paradigm shift in philosophy away from food for the poor, which addresses the symptoms of poverty, not causes, to creation of wealth...*" (Edwards 2002). From providing food to generating income implies moving from low-yield small-scale farming practice to larger-scale, higher-yielding practice (New 2003).

The possible future of small-scale farms includes empowering them to stay in the market, to upgrade, choose a market differentiation strategy, or to consolidate (Huang *et al.* 2012). Five strategies to improve small-scale farmer livelihoods were summarised as intensification, diversification, expansion, off-farm employment (i.e. part-time farming), and a complete exit from the agricultural sector (Dixon *et al.* 2001). A conceptualisation of development as involving three complementary processes for small-scale farms was proposed, which are 'hanging in' by keeping farming at a low level, 'stepping up' by upgrading farming with strategies such as commercialisation and specialisation, and 'stepping out', by leaving farms and entering paid employment off-farm (Dorward 2009).

One common mistake of any policy focus is ignoring one key necessity for labour productivity growth: successful migration out of agriculture and rural areas (Collier & Dercon 2009). If a farm is too small, no matter how efficiently the farm is managed, it's difficult for farmers to make a good living and the best outcome maybe seeking an off-farm job, even if farmer doesn't see it that way

(Gietema 2006). Market forces in the context of globalization do not guarantee competitiveness, nor do they guarantee smallholder participation (World Bank 2008).

9.4. Social, economic background

Sustainable development is consistent with a synergic socio-political interaction (Mampan *et al.* 2011). Economic development is generally accompanied by a subsequent decline in the agricultural share of national GDP (Stentiford *et al.* 2012). In China the agriculture share in national GDP dropped from more than 30% around 1980 to around 10% in last few years, along with employed population in agriculture declining from 69% in 1980 to 33.6% in 2012. The urban population surpassed the rural in 2011 (NSBC 2013).

Although China is still a 'global sweatshop' which specialises in labour-intensive commodities, the structure of industry and trade are upgrading into high-tech and heavily engineered machinery and electronics (Li *et al.* 2012). Along with this economic development, labour shortages and increased wages have become widespread (see Chapter 3), affecting agriculture and this was detected in the field survey (see Chapters 5 and 6).

It was believed that while in countries where is labour shortage, large-scale farms can increase food security through high productivity and price reduction, and reduce poverty through job creation (Wegner & Zwart 2011).

9.5. Food safety

Progress to secure its food security in recent decades by China has been recognised, but a focus on food safety is more recent (Gale & Buzby 2009). Aquatic product food safety emerged as an issue with the needs of the export trade, and the uncovering of various food safety scandals. These included the ban on Chinese shrimp exported to the EU in 2002 after the detection of chloramphenicol residues, and in 2003, the refusal of eel imports to Japan after enrofloxacin residues were detected. Along with rising consumers' awareness and more transparent information, more aquatic food safety issues have emerged in the domestic market. Drug residues in farmed turbot in 2006 caused major damage to the industry and a financial loss of more than one billion CNY (Ma & Zhang, 2012). These events forced the Government to prioritise aquatic food safety issues for both export and domestic market, and a series of action plans, regulations, and certification systems were enacted (Hanson *et al.* 2010; Pan *et al.* 2011; Gale & Buzby 2009). Safety standards for exports are generally higher and more stringently enforced than those for domestic food in China (Gale & Buzby 2009). However, domestic consumer have also became more aware of food safety (Ma & Zhang, 2012).

As elaborated by Steinfeld *et al.* (2006) the governments' policy needs to fit into the social and economic situation. Policy needs to be rebalanced among four dimensions, namely "food supply", "food safety", "environment" and "social/poverty concerns" (Figure 9.4). As society becomes more industrialised, greater focus on food safety and the environment is needed rather than food supply and social/poverty concerns. Once industrialization of the aquaculture sector begins, the smallholder sector tends to diminish in relative importance (Edwards 2010). A decline in smallholder aquaculture may improve food safety as a recent study found they lack knowledge of food safety (Rico *et al.* 2012).

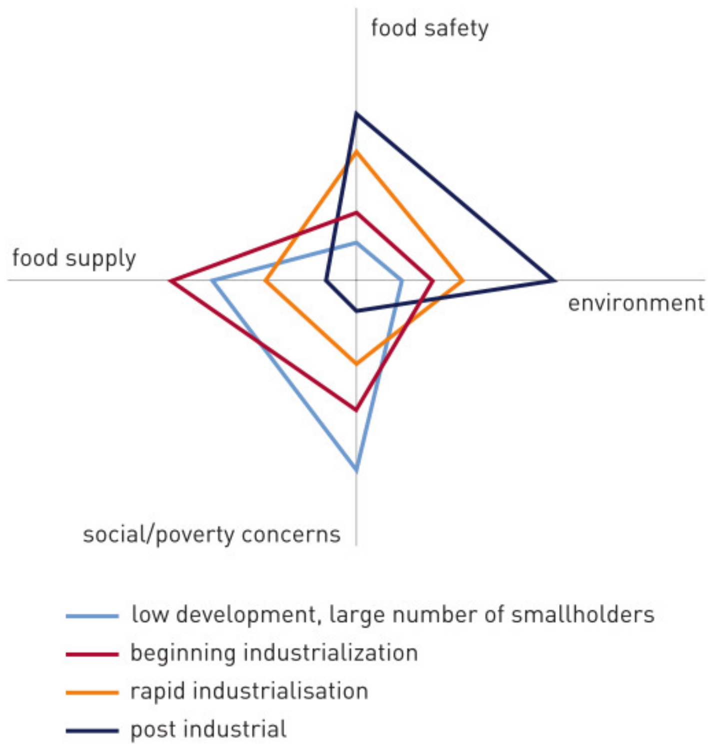


Figure 9.4 Shift in livestock policy objectives in relation to economic development

(Source: Steinfeld *et al.* 2006)

9.6. Environment

According to Figure 9.4, aquaculture development needs be balanced among all four dimensions, which implies the nature of aquaculture development does pose trade-offs between social or economic benefits and environmental impacts. Sustainability in aquaculture can therefore only be weak sustainability (=economic sustainability) (Bell & Morse 2008). However, environmental protection, a form of strong sustainability, is equally important, as aquaculture development depends on a sound environment.

This study shows shrimp and tilapia farming value chains currently consider very little about environmental protection: for example, there is almost no on-farm discharge water treatment in all farms. The environment has been a weak point in China's journey to sustainability, with unbalanced development during the “Green Revolution”; there is urgent need to avoid this in the aquaculture industry.

However, according to the “*Environmental Kuznets Curve*”, increased pollution seems to be inevitable during development from a low income society to a medium and high income one (Dasgupta & Laplante 2002). After reaching the peak point of pollution level, increasing incomes will lead to pollution levels falling (Figure 9.5).

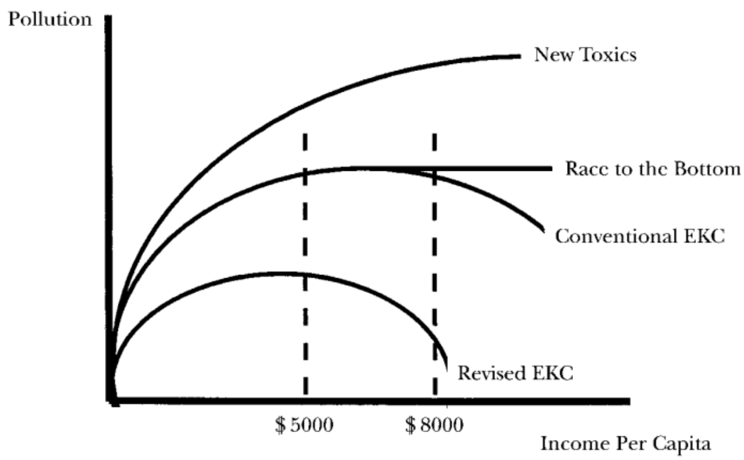


Figure 9.5 Environmental Kuznets Curve (EKC): different scenarios

(Source: Dasgupta & Laplante 2002)

Conventional EKC: the baseline EKC in which pollution level start to reduce after per capita income reached USD 5,000 - 8,000.
Revised EKC: growth generates less pollution in the early stages of industrialization and pollution begins falling at lower income levels
Race to the Bottom: EKC will rise to a horizontal line at maximum existing pollution levels
New toxics: overall environmental risks from these new pollutants may continue to grow even if some sources of pollution are reduced

Different development scenarios could change Environmental Kuznets Curve significantly, changing the peak point of pollution and/or changing the point of inflection allowing pollution to decline from a lower income level. The productivity and efficiency analysis of different farming systems and farm scales could be a reference point for future development scenarios. For example, high level shrimp farming systems have much higher land and labour productivity but are less efficient in energy input. LCA research results also provided suggestions: for example, because aquaculture feed is the single greatest contributor to environmental impacts, feed efficiency is much more important than farm level energy efficiency. Thus, certain high energy consumption facilities such as aerators could raise feed efficiency, and improve overall environmental performance.

9.7. Farmers organization

Agriculture cooperatives and group actions are important for development, improving farm performance significantly (Garrido 2007; Parliament *et al.* 1990; Srinath *et al.* 2000; Staatz 1987). Small-scale farms can enhance competitiveness and achieve improved economies of scale by collaborating and through working as clusters of organisations (Berdegué Sacristán 2001; Tain & Diana 2007). Collective action through farmers' organizations such as "cluster management" and group certification can help small-scale farmers overcome challenges related to market liberalization, globalization and increasingly stringent quality and safety requirements for aquaculture products (Kassam *et al.* 2011). A group farming approach among small-scale shrimp farmers in India was as an effective way for extension intervention to educate farmers on sustainability while helping them to improve their farming practices (Srinath *et al.* 2000; Umesh *et al.* 2010)

In China, less than 3% of farmers were members of professional association or cooperatives in 2005 (Shen *et al.* 2006), but this increased quickly to nearly 10% by 2008 (Huang *et al.* 2012). In this study, very few farm cooperatives were found in tilapia and shrimp value chains. There were a few tilapia farm cooperatives organized by processors but as these were CIQ registered, export orientated producers they were all large-scales.

Even with farmers' organisations, small-scale farms remain weak financially and in terms of technical capacity. Also farmers' organisations in many developing countries have been used as a ruling tool and manipulated by government (Wegner & Zwart 2011). Unsophisticated small-scale farms have limited individual capacity and often lack of enthusiasm for collective approaches (Muir 2005). Farmers' organizations of small-scale farmers may not be helpful in relieving environmental impacts, as individual farming activities of many small-scale farms can also aggregate into the cumulative impacts with greater environmental effects (Diana *et al.* 2013; Peterson & Lowe 2009).

Besides farmers cooperatives, contract farming between large companies and small-scale farms was seen as one ways to raise farmers' income (Glover & Kusterer 1990; Miyata *et al.* 2009). There is scope for large-scale farmers as commercial enterprises to interact with smaller scale farmers by integrating them to large-scale economies in processing and marketing (Collier & Dercon 2009). Wide range collaborations between large-scale investor and local small-scale farms and communities can be achieved in output processing, packaging and marketing, rather than in production (Wegner & Zwart 2011). Increasing vertical integration has recently been observed in the sector, with feed companies expanding the range of support services and inputs they provide to farmers and dealers in order to capture greater market share (Mamun-Ur-Rashid *et al.* 2013). However, it was reported that 80% of large-scale companies leading contract farming had failed in China due to unstable relationships and unbalanced power between companies and farmers (Wang 2009). At the same time, contract farming does not in itself change the status of small-scale and scattered farming practice, and cannot resolve the food safety problem (Lin & Ren 2006). The notorious food scandal of melamine contamination in milk product in China occurred within small-scale farms working under contract farming (Wang 2009).

9.8. Future consolidation

Due to the natural course of business, farm scale tends to grow and farm consolidation is likely in the foreseeable future (Gloy *et al.* 2002). World aquaculture is still dominated by small-scale farms, but the international trade and investment will likely make large commercial farms become more common (Pillay 2000). Farm consolidation was observed as declines in the number of farms, increases in productivity, and increases in farm size (Gloy *et al.* 2002). Underpinning farm consolidation is the survival of profitable farms willing to enlarge their business and the exit of less profitable farms (Gloy *et al.* 2002). It may be a response to price uncertainties in the market to reduce unit cost of production (Bondad-Reantaso *et al.* 2012), or due to large-scale farms becoming more efficient and developing longer-term market relationships. Small-scale farms can become increasingly uncompetitive and vulnerable to takeover under these conditions (Muir 2005) especially if there is a significant 'pull' factor to off farm employment (Rigg 2006). Larger farms can significantly increase returns to land due to economies of scale, while landless households can benefit from increased returns to labour (Niragira *et al.* 2013).

Large-scale farms usually have more employees who are to some degree specialised such as drivers and accounts, large-scale farms are more labour productive and can drive food prices down on a global scale (Belton *et al.* 2012; Wegner & Zwart 2011). The division of labour can improve labour productivity significantly (Smith 1776). Diversification of farming activities should invariably improve the utilization of labour (Noble 2009). This study also found large-scale farms had more hired labour and specialized manager and technicians, and that any trend to specialisation is constrained in contexts where small-scale farms dominate.

The salmon farming industry in Europe is a good example of the transition from smaller scale production to large-scale production after significant consolidation, and upgrading with innovative technologies, producing better quality and cheaper products, more educated labour, and mergers in the sector (Roth 2002), and the survival of only a few, larger companies (Naylor & Burke 2005).

In developing countries, there is also a trend to consolidation in the aquaculture sector. For example the striped catfish farms in the Mekong Delta are dominated by small-scale farms, more than70% striped catfish farms were less than five ha in 2008 (Phan *et al.* 2009) but the proportion of total farming area has sunk to 30% by 2012 (Phan 2014). Farm consolidation in the striped catfish farming sector was driven by declining farm gate prices leading to economic losses and an inability to increase investment by small-scale farms (De Silva & Phuong 2011).

In China, future farm consolidation is needed to increase farm scale by enhancing both land-use rights and land-rental markets (Huang *et al.* 2012).

9.9. Land reform is needed for consolidation

Land related policy, legislation, and implementation arrangements are the most important factors determining the pattern and distributional consequences of agricultural growth (International Bank for Reconstruction and Development & World Bank 2009). Well-defined individual or collective rights (property, access, human, labour) would act as incentives for the private and public promoters of aquaculture development to make decisions with a more secure and informed basis (Diana *et al.* 2013). Secure transferable land rights can protect small-scale farmers’ interests, enable the land to transfer to entrepreneurial farmers who can use it most productively, and provide incentives to invest in increasing land productivity (International Bank for Reconstruction and Development &

World Bank 2009). In Vietnam and Thailand, the clarification of property rights significantly promoted agriculture development (Wegner & Zwart 2011).

The land reform and family-contract responsibility system was the main driver for the high speed growth in agricultural productivity in the early period of economic reform in China (Lin 1992; Huang *et al.* 2012; Fan 1991). Land was allocated to farm households by local villages on the basis of the number of family members, the amount of labour, or desire and/or ability of the household to engage in agricultural production (Rozelle *et al.* 2002). These reforms separated land ownership and land-use rights, although land-use right is transferable, land transactions were prohibited explicitly or tacitly (Huang *et al.* 2012).

It is believed that the ill-defined property rights and weak protection of land rights can lead to land prices remaining well below their real value, and prevent large-scale farms from expanding (Wegner & Zwart 2011). The current Chinese laws do not define aquaculturists' rights clearly, often leading to them being disadvantaged in protecting their rights from interference, obtaining long-term investment, and preventing harmful trespass and water pollution from external sources (Liu, 2007). Although land-related laws have been enacted to protect land rights, change has been slow at the grass roots in their application. China's land property rights that prevent farmers selling or buying land or ponds (Huang *et al.* 2012), have probably acted to slow aquaculture development away from its small holder origins.

The aquaculture license system initiated since the enactment of the Fisheries Law in 1986 (Zhang & Rørtveit 2005), which was seen as part of farmers' land right confirmation (Li 2011). However, progress to build this system was very slow due to unclear property rights between collective owned land, national owned land and private plots. After the Property Law was passed in 2007, progress has accelerated and it is reported that by 2010, over 60% aquaculture farms have now been certified with aquaculture licenses (Li 2011). Because the slow progress in implementing a license system, administration and management in China were seen as relatively weak and inefficient (Zhang & Rørtveit 2005).

Another conflict point has been the issue of national food security being used to constrain aquaculture development. The land protection policy prevented conversion of crop land to fish pond. Large area fish ponds build by farmers privately without government permission was reclaimed to farm land (Bai 2009; Zhao & Fan 2013). This demonstrates that in the agriculture sector, the planned rather than market economy still dominates and that farmers actually don't have full rights to their land.

Current land policy has also fuelled growth in the so-called "floating population" or internal migration. Migrant labourer are mainly farmers who remain registered in their home communities but who work as temporary employees elsewhere (Goodkind & West 2002). The floating population increased from 121 million in 2000 to 221 million in 2010 and 235 million in 2012 (NSBC 2013). These high numbers reveal abundant off-farm employment opportunities.

Small-scale farming activities can't increase incomes of most rural households (Huang *et al.* 2012). The land related laws and regulations are seen as insufficient to fully address rural issues surrounding land tenure rights. The need for breakthrough rural land reform that ensures more fundamental change is needed in the future (Dean & Damm-Luhr 2010). The new land reform started from 2008, with the basic idea based on the household contract responsibility system to develop the land transfer and trade system and encourage large-scale operations through farmers' cooperatives (Baidu Net 2013).

An alternative to development of land reform and more efficient food production in China is to seek resources elsewhere. Although the farm consolidation was expected, the so called 'superfarms' with more than thousands hectares lands developed in Africa was fundamentally geopolitical rather than commercial and are not an appropriate for agriculture growth (Collier & Dercon 2009). Future policy reforms or institutional innovations must fulfil the local social economic situation, and stakeholders' participation is needed to develop a shared vision and a long-term strategy to realize an appropriate balance between industry, the market, and civil society (Wegner & Zwart 2011).

9.10. Value chain evolving

The consolidation of farms and introduction of cost-saving but capital intensive technologies can only be achieved in a mature society with independent banks and public management and legal systems to avoid any unexpected economic risks. Well-educated human resources are the precondition for these transitions (Roth 2002). Without support for social economic development, aquaculture development is unrealistic. Consolidation is needed for not only farms, but all sectors in the whole value chain.

As with the farming sector, small-scale traders and scattered value chain actors also dominate agri-food value chains in China. Meeting the growing demand for improved food safety in both domestic and export markets remains a challenge (Huang *et al.* 2012). A survey conducted in Beijing area in 2004 showed that around 80% of agriculture farms sold their products to traditional small buyers, and no farmer sold directly to supermarkets (Wang *et al.*, 2009). Another survey conducted in Shandong province in 2005 found no apple farm signed supply contracts, and less than 30% of grape farms had formal or oral supply contracted (Huang *et al.* 2008). There were at least 400,000 food processing enterprises in China, most of which had ten or fewer employees (Gale & Buzby 2009), and which mostly lacked the capacity to comply with HACCP standards (Luo & Cheng 2011).

The undeveloped aquatic product distribution system in China has many actors (Ye *et al.* 2011) but unsophisticated infrastructure, inefficient logistics and, as an outcome potential hygiene problems. A tradition of marketing live fish and the greatest volume being sold through local food market supports a myriad of small wholesalers and retailers; it was estimated that 58% aquatic products were still distributed by sole traders in wet markets as recently as 2006 (Zhou, Lv, & Lu, 2008). This network of small-scale and scattered food traders and suppliers increases the challenge of disseminating standards, monitoring production, and building a traceability system (Gale & Buzby 2009; Huang *et al.* 2012; Li *et al.* 2010). Certification for individual small-scale value chain participants is prohibitively expensive and impractical (De Silva & Phuong 2011; Diana *et al.* 2013; Kassam *et al.* 2011), and China's preference for live fish makes quality supervision even more difficult and expensive (Bean & Wu 2006).

Compared to small and scattered seafood value chain actors in China, the salmon value chain in Europe is already vertically and horizontally integrated. Salmon supply chains are the most industrialised in aquaculture, with an increasing degree of vertical coordination from salmon farms to the supermarkets, a model that has more similarities with manufacturing and the most industrialised value chains in agriculture (Kvaløy & Tveterås 2008).

Due to China's vast size in both territory and economy, there is no company dominating seafood value chain as CP does in Thailand. Success stories are also lacking such as the promotion of "ruby fish" in Thailand. It is reported that little branding of live seafood takes place in China (New Zealand Trade and Enterprise 2012). However, on a global scale, national, regional, and global supply chains are being radically altered by the "supermarket revolution", bypassing traditional markets where smallholders sell to local markets and traders (World Bank 2008). As successful examples exist such as salmon in Europe and ruby fish in Thailand, and along with further urbanisation, the future consolidation in the seafood market sector can be expected. The future seafood value chain need to focus more on quality, branding, marketing and distribution-systems, which means that a more knowledge based seafood industry will develop (Bjørn *et al.* 2005).

9.11. Discussion on the limitations of this study and suggest for future studies.

Most of primary data came from an initial integrated and follow on in-depth survey structured on the same sampling approach (Murray 2013). The sampling was largely based on farm clusters, with few large-scale farms outside these clusters. Farm clusters in a given area were characterised by many small-scale farms, which was seen as conducive to aquaculture (De Silva & Davy 2009). However such a sampling approach may have led to unbalanced sampling and cause scatted farms excluded in the study. The differences between farms gathered in farm clusters and farms outside these clusters may need further research.

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11. Appendices

Appendix 1 Contributions to research design, data collection, data analysis and writing

	Research design	Data collection	Data analysis	Writing
Chapter 3	Wenbo Zhang, Peter Edwards	Wenbo Zhang	Wenbo Zhang	Wenbo Zhang, Francis J. Murray, Liping Liu, David C. Little and Peter Edwards
Chapter 4	Wenbo Zhang, David C. Little	Wenbo Zhang	Wenbo Zhang	Wenbo Zhang, Francis J. Murray, Liping Liu, and David C. Little
Chapter 5	Wenbo Zhang, Francis J. Murray	Wenbo Zhang, Zongfeng Zhang, Liangjie Zhao, Peiqiao Jia, Donghong Ma, Kang Li, Teng Luo, Xiancheng Yuan, Qiuyan Li, Rui Qu, Yan Li, Guangxue Zhao, Shikai Li, Zhenfu Chu, Patrik Henriksson, Emilie Devic	Wenbo Zhang	Wenbo Zhang, Francis J. Murray, Liping Liu, and David C. Little
Chapter 6	Wenbo Zhang, Francis J. Murray	Wenbo Zhang, Zongfeng Zhang, Liangjie Zhao, Peiqiao Jia, Donghong Ma, Kang Li, Teng Luo, Xiancheng Yuan, Qiuyan Li, Rui Qu, Yan Li, Guangxue Zhao, Shikai Li, Zhenfu Chu, Patrik Henriksson	Wenbo Zhang	Wenbo Zhang, Francis J. Murray, Liping Liu, and David C. Little
Chapter 7	Wenbo Zhang, Patrik Henriksson	Wenbo Zhang, Patrik Henriksson, Zongfeng Zhang	Wenbo Zhang, Patrik Henriksson	Wenbo Zhang, Patrik Henriksson, Jeroen Guinée, Francis J. Murray, Qigen Liu, and David C. Little
Chapter 8	Wenbo Zhang, Francis J. Murray	Wenbo Zhang, Francis J. Murray, Ting Wang and Jing Lin	Wenbo Zhang	Wenbo Zhang, Francis J. Murray, Liping Liu, and David C. Little

Appendix 2 Baseline survey questionnaire. Please see pdf file in attached CD

Appendix 3 Follow-on survey questionnaire. Please see pdf file in attached CD

Appendix 4 Five scored sustainability indicators (SIs) by different categories and levels, and DPSIR (driving force (D), pressure (P), state (S), impact (I) and response (R)) framework.

Category	Level	DPSIR	Sustainability indicators
Economic	Farm level	S	Farm yield
		S	Duration of production cycle
		I	Production cost
		P	Disease frequency
		S	Growth rate of fish or shrimp -
		I	Profitability
		I	pH of farm water
		S	Total feed input
		I	Percentage of harvest of fry/fingerlings/pl which are harvested compared to original stocking numbers
		R	Using aerators
		S	Farm gate price
		S	Stocking density
		S	Total sales
		D	Total investment
		I	Mortality rate
		S	Total production
	Supply chain level	R	Number of selection programmes in hatcheries
		S	Protein level in the feed
		S	Survival rate of seed in new water environment
		R	Time need for collection of payment
		S	Male ratio of tilapia seed
		S	Feed cost
		S	Price of seed
		S	Productivity of seed
		S	Electricity price
		S	Frequency of power shut
		S	Power cut duration
		S	Voltage of electricity power
	Market level	S	Number of customers of small-scale enterprises
		I	Customer satisfaction
		I	Growth rate of sales to domestic market
		S	Numbers of seafood related branches of overseas companies in china

		I	Compare prices at usual and holidays
		R	Range of distribution
	Macro level	S	Price of raw materials
		S	Labour cost
		S	Pond rental cost
		R	Numbers of species which are best suited to aquaculture
		S	Exchange rate
		P	Changes in exchange rate
		S	Salaries
		S	Volume of seafood trade in international market
		S	Fuel cost
Environment	Macro level	P	Number of cloudy days
		D	Amount of rainfall
		P	Water availability in reservoir during winter months
Social	Farm level	I	Proportion of farmers achieving profit
		R	Join cooperatives
	Macro level	S	Number of feed mills
		S	Number of feed brands in the market
		S	Proportion of small-scale farms
		S	Proportion of small-scale feed mills and processing plants
		R	Quantify the volume of raw materials supplied by international suppliers
		R	The level of automation of the machines in the production line
		S	Numbers of reliable broodstock providers
		S	Number of hatcheries in same area
	Government level	R	Frequency of government checking
		R	Pollution free aquaculture certification
		R	Frequency of meeting with government staff
		R	Training opportunities offered

Appendix 5 Formula of tilapia feed (primary data) and pig feed

	Name	Unit	Value	Uncertainty
Tilapia feed	Soybean meal	kg	259	L(0.206)
	Soybean oil	kg	22	L(0.552)
	electricity, low voltage	kWh	131	L(0.592)
	Feed minerals	kg	1.00E+03	-
	Wheat bran	kg	25	L(0.605)
	Wheat flour	kg	142	L(0.605)
	Maize flour	kg	46	L(0.605)
	DDGS	kg	16	L(0.605)
	Cassava chips	kg	27	L(0.605)
	Rice bran	kg	20	L(0.605)
	Fishmeal, unspecified source	kg	68	L(0.206)
	Groundnuts	kg	77	L(0.206)
	cotton seed	kg	68	L(0.206)
	Fish oil, from tilapia by-products	kg	5	L(0.552)
	hard coal, burned at feed mill	MJ	489	L(0.769)
	Rape seed cake	kg	144	L(0.206)
Pig concentrated feed	Soybeans BR, at port	kg	145	L(1.05)
	Soybean meal	kg	553	L(0.254)
	Soybean oil	kg	4.12	L(1.05)
	electricity, low voltage	kWh	91	L(0.122)
	Feed minerals	kg	4.44E+03	L(0.152)
	Fishmeal, unspecified source	kg	142	L(0.216)
	cotton seed	kg	22	L(1.05)
	Salt	kg	92.5	L(0.845)
Pig pelleted feed	Soybean meal	kg	161	L(0.298)
	Soybean oil	kg	3.62	L(1.46)
	electricity, low voltage	kWh	91	L(0.122)
	Feed minerals	kg	1.00E+03	-
	Wheat bran	kg	50.7	N(67.8)
	Wheat flour	kg	21.2	L(1.36)
	Maize flour	kg	628	N(94.1)
	DDGS	kg	7.9	L(1.41)
	Paddy rice	kg	4.2	L(1.72)
	Rice bran	kg	22.2	L(1.25)
	Fishmeal, unspecified source	kg	8.7	N(1.07)
	cotton seed	kg	7.72	L(1.4)
	hard coal, burned at feed mill	MJ	1.08E+03	L(0.112)
	Rape seed cake	kg	7.42	L(1.35)
	Salt	kg	1.21	N(1.26)
Pig all feed mix	Soybeans BR, at port	kg	5.01	L(1.18)
	Soybean meal	kg	34.2	L(0.946)
	Feed minerals	kg	1.00E+03	-

Wheat bran	kg	67	L(0.788)
Maize flour	kg	597	L(0.11)
Rice bran	kg	11.1	L(1.18)
Rape seed cake	kg	0.537	L(1.18)
Concentrated pig feed	kg	56.5	L(0.929)
Pig formulated feed	kg	225	L(0.18)

Note: L=lognormal distribution, N=normal distribution Source: (Cao *et al.* 2008; He 2008; Xie *et al.* 2009; Liu *et al.* 2009; Yue & Wang 2011; Wang 2012; Zheng *et al.* 2013; Liu *et al.* 2012; Wang 2010; Li *et al.* 2003; Ye *et al.* 2011; Zhao 2008; Yang & Xiao 2010; Huang *et al.* 2010; Zongmin Liu *et al.* 2011; NDRC 2013)

Appendix 6 Tilapia and shrimp farming record-keeping book. Please see pdf file in attached CD


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Appendix 7 Record-keeping survey questionnaire. Please see pdf file in attached CD

Appendix 8 Record-keeping workshop questionnaire. Please see pdf file in attached CD